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# Surface Layer Stability Transition Research Minimum Neutral Event-to-Sunrise Time Interval: 2001 September Case Study

by Gail-Tirrell Vaucher and Manny Bustillos

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# NOTICES

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## Preface

In 2001, the U.S. Army Research Laboratory, Meteorological-sensors Integration Team, conducted a series of three field tests in the southwestern desert of the United States. The purpose was to identify, characterize, and exploit repeatable atmospheric patterns found in the lowest layer of the Boundary Layer, the Surface Layer. The repeatable pattern selected was the Surface Layer Stability Transition. Each field test was timed with the purpose of validating a seasonal extreme in the annual morning Stability Transition (ST) timing cycle. The first seasonal minimum (Equinox month-March 2001) and the seasonal maximum (Solstice month-June) were documented in separate Technical Reports. This Technical Report focuses on the second seasonal minimum occurring in the Equinox month of September.

Each field test served as a building block in the overall goal of modeling the ST. The information gained from these field tests has three fundamental links to the U. S. Army and to the military in general:

1. This research expands on U.S. Army Chief of Staff Shinseki's vision.
2. The knowledge of exploitable atmospheric characteristics, such as an ST, enhances electro-optical weapon effectiveness and efficiency.
3. The accurate ST forecasts provide crucial initializing information for atmospheric models that forecast chemical and biological weapon effects, as well as transport and diffusion effects.

# Acknowledgements

Appreciation is extended to the Meteorological-sensors Integration Team (MIT) members for their successful execution of the 2001 June Atmospheric Surface Layer Field Test. The MIT Team members included: Robert Brown, Edward Creegan, Doyle “Scott” Elliott, Alfred Gutierrez, David Quintis, Gail Vaucher (Team Leader) and Jimmy Yarbrough. Also, appreciation goes to Ms. Nancy Fudge, for her efforts in linking the remote site field test activities with the demands of the standard work hour routines.

## Executive Summary

U.S. Army Chief of Staff Shinseki stated that his U.S. Army vision was to see first, act first, and kill first. In GovExec.com's *Daily Briefing*, Freedberg Jr. wrote that the most powerful, accurate and quickest weapon on the planet is the laser. Both military concerns have one major hurdle, "seeing" through the atmosphere. The Surface Layer Stability Transition (SLST) Research has been investigating naturally occurring atmospheric patterns that enhance or detract from the successful "seeing" mission. These same Stability Transition (ST) patterns also provide knowledge of when the effects of chemical and biological weapons will shift from foe (toxic concentrations in a limited area) to friendly (non-toxic concentrations in a broad area), and vice versa. Likewise, initializing the convective Boundary Layer growth phase (ST) impacts civilian and military Atmospheric Dispersion/Diffusion Model accuracy. For the military, knowing when a smoke screen will "clear", for example, could prove to be a significant strategic advantage on a battlefield.

In 2001, the Meteorological-sensors Integration Team conducted three field tests with the primary purpose of characterizing, modeling, and exploiting repeatable patterns in the lower portion of the Atmospheric Boundary Layer. The repeatable patterns investigated were the morning ST, or Neutral Events (NE). The 2001 September 19–21 dates were selected based on a forecasted minimum time interval between the local Sunrise and an Ideal Case stability transition. Two other correlated field tests addressed the seasonal sunrise-to-NE time interval maximum and alternate minima (2001 June and March, respectively). These latter Tests were documented separately.

The SLST research pursued two measurement and analysis methods: Eulerian (Tower data) and quasi-Lagrangian (Rawinsonde data). The September 2001 results yielded both Ideal and Non-ideal ST condition cases. All observed NE served to validate the ST Forecast Model. Also gleaned from the data was a constructive characterization of the atmospheric conditions prompting the more difficult to understand Non-ideal Multiple and Extended NEs. In short, while reduced-insolation was empirically linked with the Multiple-NEs, the Extended-NEs were associated with increased ground and low-level moisture. The Test results documented here serve as a useful building block in support of their primary purpose.

# 1. Introduction

This publication is the last of three technical reports documenting the 2001 Surface Layer ST Field Tests. Sections 1.1 and 1.2 are reproduced from the *Surface Layer Stability Transition Research, Minimum Time Delay from Sunrise: 2001 March Case Study* (Vaucher et al., 2003).

## 1.1 U.S. Army Interest in Atmospheric Stability Transition Research

Atmospheric Stability Transition (ST) Research links to military interests in at least three arenas. In the July 2002 *Army Materiel Command Newsletter*, U.S. Army Chief of Staff Shinseki stated that his vision for the U.S. Army was "to see first, act first, kill first...To see first, we must have persistent and pervasive intelligence-gathering capabilities" (Burlas, 2002). The atmosphere is one of the major hurdles retarding the efficiency of "seeing first." The Boundary Layer Exploitation Task-Surface Layer Stability Transition (SLST) Research has been investigating naturally occurring atmospheric patterns that enhance or detract from the successful "seeing first" capability. Under favorable atmospheric conditions, target identification is potentially done quicker, making the last two actions of the Shinseki's U.S. Army vision more efficient and effective.

Sydney Freedberg Jr. wrote in his GovExec.com *Daily Briefing*, that the most powerful, most accurate and quickest weapon on the planet, the laser, has one major obstacle, the weather (Freedberg, 2001). To quantify the atmospheric impact on this, or any other electro-optical (EO) weapon, one needs to understand a parameter called "seeing". To an astronomer, "seeing" is the arc second or angle occupied by the star image at the full-width and half-maximum of its intensity profile, as viewed from a specific point in the atmosphere (Businger et al., 2002). "Seeing" improves or degrades with changes in the atmospheric optical turbulence strength and location as quantified by profiles of the refractive index structure function $C_n^2$. The SLST Research grew out of EO propagation research, and now serves as a building block for understanding and forecasting the naturally occurring atmospheric cycles that are both favorable and non-favorable for the laser and any subset of this weapon type.

Finally, a significant urban warfare hazard is the release of chemical and biological weapons. The atmosphere, specifically the Boundary Layer convection, can enhance or detract from the weapon's effectiveness. From a military perspective, knowledge of a ST means knowledge of when the chemical and biological weapon's effect will shift from foe (toxic concentrations in a limited area) to friendly (non-toxic concentrations in a broad area), and vice versa (Angevine et al., 2001).

Likewise, initializing the convective Boundary Layer growth phase (the ST) is a primary interest to civilian and military Convective Boundary Layer and Atmospheric Dispersion/Diffusion

Modelers. Model results often reflect the initial input accuracy. For the military, knowing when a smoke screen will "clear", for example, could prove to be a significant strategic advantage on a battlefield. Thus, the ST pattern ties to both military and civilian applications (Angevine et al., 2001). Additional civilian interests will be described in the next section.

## 1.2 Civilian Interest in Atmospheric Stability Transition Research

The Atmospheric Boundary Layer behavior during the period between the fully developed convection of mid-day and the stable conditions of the nocturnal Boundary Layer is poorly understood, but is of interest in several fields, including chemical and pollutant modeling (Grimsdell and Angevine, 2002). Grimsdell and Angevine focused their work on the afternoon ST in agricultural environments. However, their assessment regarding the poor understanding is also true for the morning Surface Layer ST in a desert environment.

Finally, in the June 2002 *Bulletin of the American Meteorological Society*, Businger et al., describe the unique weather forecasting requirements for the highly technical stellar viewing at Hawaii's Mauna Kea Observatories. Clear air turbulence in both the free atmosphere and in the Boundary Layer were flagged as causes for image distortion and blurring for their ground-based telescopes. Forecasting the observing quality for seeing parameters accurately is a key factor in the successful scheduling of these very expensive civilian optical and infrared instruments. Knowing when the atmospheric impact would be minimal, such as during a ST, would be a significant improvement and enhancement for the astronomical community (Businger et al., 2002).

## 1.3 Purpose and Overview

This technical report is part of the U.S. Army Research Laboratory's (ARL) Fiscal-Year (FY) 2002 Boundary Layer Exploitation Task. The Task's governing purpose was to characterize, model and exploit the lower portion of the Atmospheric Boundary Layer, the Surface Layer. The specific topic targeted for exploitation was the Surface Layer ST. The ARL Meteorological-sensors Integration Team (MIT) conducted three ST field tests in FY 2001 (March, June and Sept 2001). Key results and new understandings gained from the last Test, the 2001 September Equinox-Atmospheric Surface Layer Field Test, are reported within this document. The Test was executed at White Sands Missile Range (WSMR), NM. One of the primary objectives for the field test was to validate the proposed Seasonal Algorithm used in the morning ST Forecast Model (Vaucher and Endlich, 1995).

## 1.4 Background of the Stability Transition Study

The following historical review of the ST study is reproduced from the Surface Layer Stability Transition Research, Minimum Time Delay from Sunrise: 2001 March Case Study (Vaucher et al., 2003).

The initial ST study was funded by the Atmospheric Science Laboratory and conducted at the U.S. Army-owned High Energy Laser Systems Test Facility (HELSTF), NM in the mid-1990s (USASL Contract). This study was prompted by an operational need to minimize the impact of atmospheric optical turbulence (AOT) on the High Energy Laser (HEL) when propagating along a 1 km path. Based on observations, the HELSTF meteorologists noted that twice a day the AOT would drop to a minimum. These AOT minima correlated closely with the morning and evening STs.

Over time, ARL meteorological operational researchers developed a "rule of thumb" approach for forecasting the morning and evening STs. This "rule of thumb" suggested that a minimum amount of AOT occurred when the atmosphere was neither stable, nor unstable, and that such a "Neutral Event (NE)" occurred 60 min after sunrise, and 40 min before sunset. While the "rule of thumb" was able to yield a ballpark accuracy, the high cost of HEL testing quickly demanded a more precise forecast. Thus, a more rigorous investigation began.

In 1994, Vaucher and Endlich published results from the first of two significant studies. According to their 2-month study, the average occurrence of the morning NE was about 70 min after sunrise. The time difference between sunrise and the associated NE ranged between 40 and 133 min after sunrise. The evening NE occurred an average of about 60 min before sunset, with a Sunset-NE time difference ranging between 98 and 12 min before sunset (Vaucher and Endlich, 1994). They also noted that there was an implied trend in their statistical findings. Consequently, a follow-on study was pursued.

In 1995, Vaucher and Endlich published the results from a 16-month AOT NE study conducted at HELSTF, NM. Recognizing the local heat flux as the primary contributor to AOT, the authors isolated three variables (Sunrise/Sunset time, Delta-T and Insolation) related to the heat flux, and observed their relationship to the NE over a 1 km desert path. The 16 m minus 2 m Temperature (T) difference (Delta-T) was examined at the start and end of the sampling path. Results reported near-surface, slightly dry adiabatic conditions present during a NE. The NE-insolation values showed that the ranges of insolation magnitudes at the Sunrise-NE were about twice those sampled at the Sunset-NE. This observation was explained as a function of the sun's elevation.

The most significant discovery of the 1995 study, with respect to ST forecasting, came while overlaying local sunrise and NE times. The minimum average time difference between local sunrise and NE was reported in the Equinox months. The maximum monthly time difference average occurred in the Solstice months. Vaucher and Endlich theorized that the skewed diurnal heating-cooling cycle of the solstice periods generated strong near-surface temperature inversions that delayed the transition into the near-dry adiabatic atmosphere required for a NE. During the Equinox, the 24-h heating-cooling cycle was nearly equal. Therefore, minimal time was needed for the day or nighttime atmosphere to transition into the near-dry adiabatic environment (Vaucher and Endlich, 1995).

Figure 1 displays the seasonal effect discovered by Vaucher and Endlich. In this figure, the Sunrise NE (SRNE) Rule of Thumb Forecast is contrasted with the actually observed NE time.

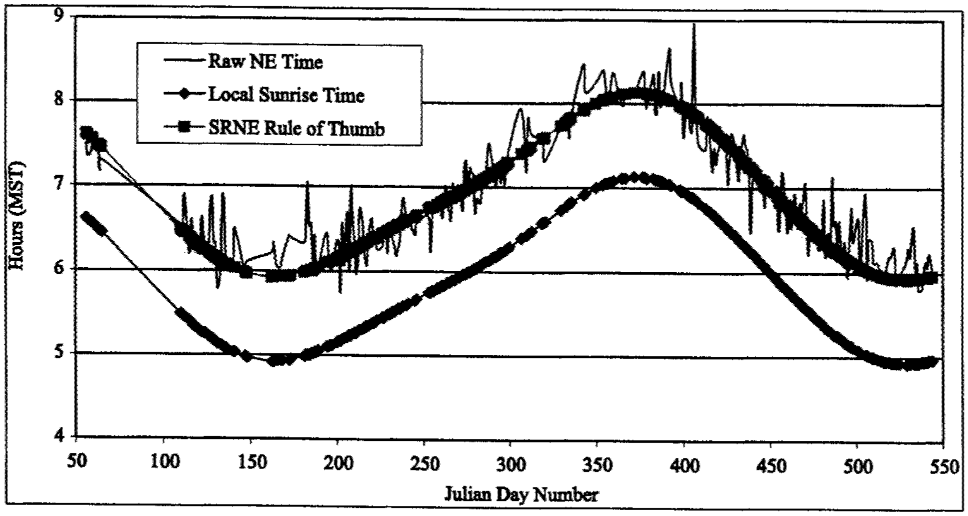


Figure 1. Local Sunrise, SRNE Rule of Thumb, and NE Times, 1994 February-1995 June (Raw Data).

To display the oscillation more plainly, figure 2 shows the "rule of thumb", the monthly averaged NE time, and the actual NEs.

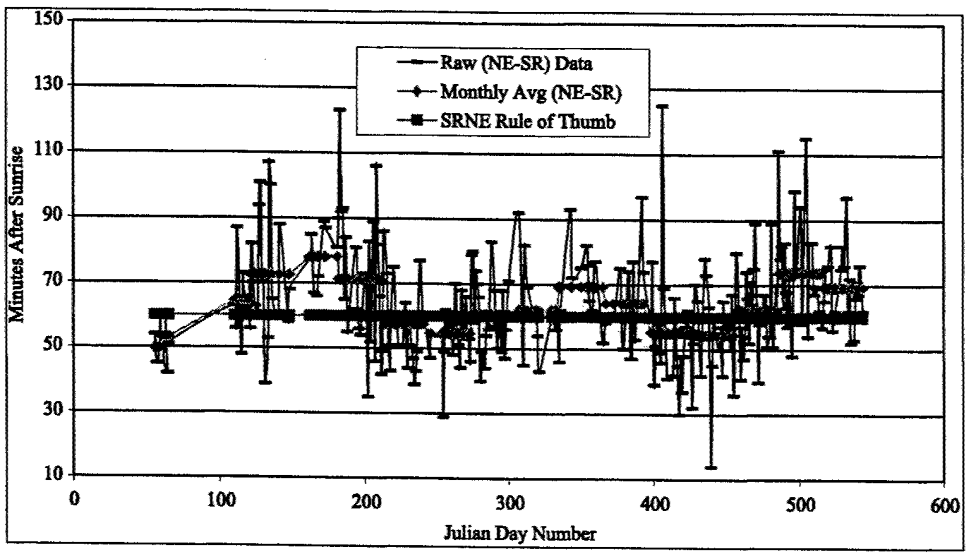


Figure 2. SRNE Rule of Thumb, Raw and Monthly Averaged NEs, 1994 February-1995 June.

Removing the actual data, figure 3 shows the annual cycle of average NE by month. Note he Equinox NE minima (September, March) and the Solstice NE maxima (June, December). The first minimum is ignored due to the lack of data for the initial month.

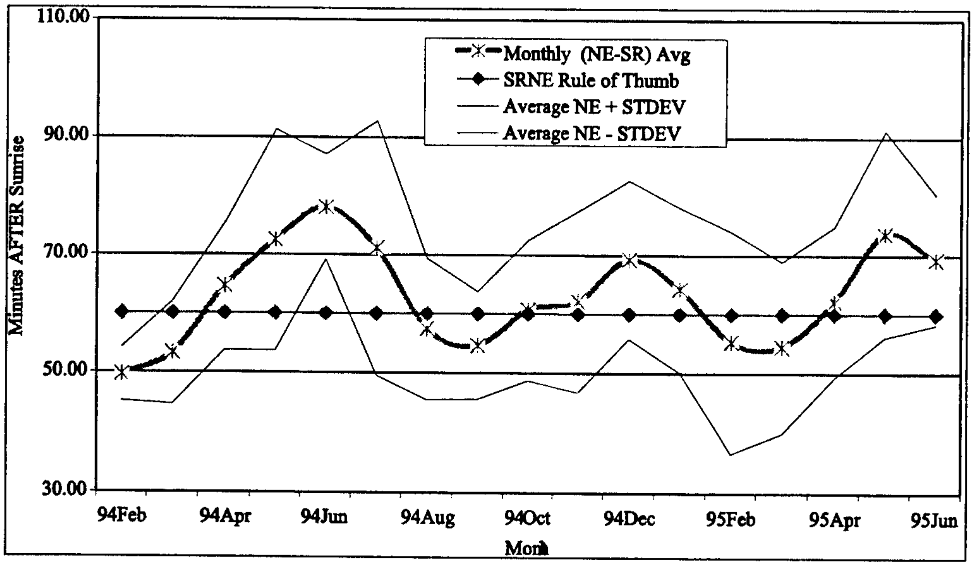


Figure 3. Monthly Averaged Sunrise Neutral Event Time Differences, 1994 April-1995 June.

Based on the 16-month study, Vaucher and Endlich updated the Rule of Thumb NE Forecast approach by introducing a seasonal correction curve. The coefficients produced by the Fourier Waveform Analysis can be found in their 1995 Battlefield Atmospheric Conference paper (Vaucher and Endlich, 1995).

The 16-month study left some unanswered questions:

1. Are the updated Rule of Thumb NE Forecast algorithms site specific? What about a non-desert environment? What about other latitudes?

2. Is the seasonal oscillation real or a coincidence?

3. The current model works under Ideal atmospheric conditions. What about under Non-ideal conditions (see section 1.6)?

ARL addressed some of these questions during the FY01 field tests. First, however, this report examines the ST character and the Ideal versus Non-ideal atmospheric conditions.

## 1.5 Character of the Stability Transition

The ST character is best understood by examining a full 24-h stability cycle. Figure 4 presents a "typical" diurnal (a March Equinox AOT time series over a high elevation desert site in the southwestern United States) and can be used as a visualization tool for the following stability cycle description. Additional information on typical stability cycles can be found in *Meteorology for Scientists and Engineers* (Stull, 2000) and *An Introduction to Boundary Layer Meteorology* (Stull, 2001).

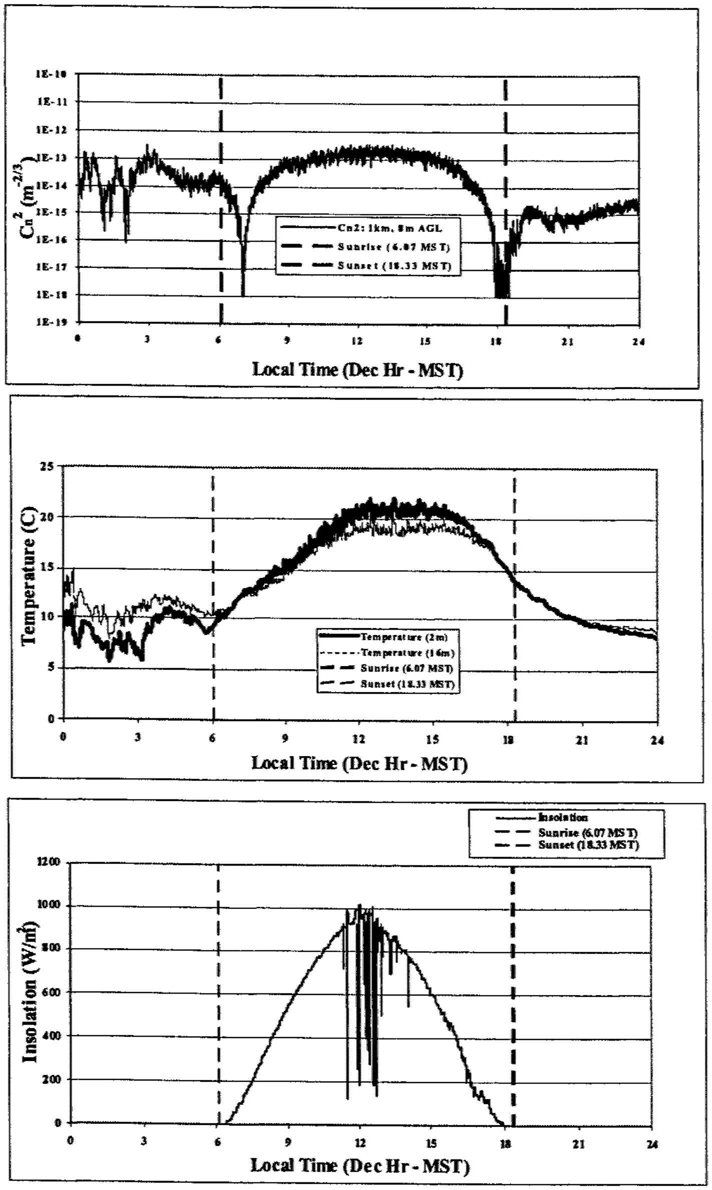


Figure 4. Coincident $C_n^2$, Temperatures, and Insolation Time Series along a 1 km path for 24 March 2001 at HELSTF, NM.

*0000-Sunrise.* Under clear skies, calm winds, and low ground moisture, the desert basin at 0000 hours Local Time is stably stratified. The coldest temperatures are at the lowest levels (Delta-T > 0). The heat flux is negative, and the AOT is a moderate-to-low level. Katabatic flow off neighboring mountains serves as a catalyst for overturning and mixing the nighttime stable atmospheric layers. The result is a mélange of density variations, which produces intermittent maxima of AOT. If winds decrease, AOT will return to the normal moderate-to-low level.

*Sunrise occurs.* The rays of sunrise start warming the ground, which radiates heat into the lowest atmospheric layer. The heat flux steadily increases, causing the stable atmosphere to become isothermal and "neutral." $C_n^2$, coincidentally, drops to a minimum. This is the morning, or Sunrise AOT NE.

*Daytime.* As the sun continues warming the ground throughout the morning, the neutral stability shifts into an unstable state. The heat flux is positive. The vertical temperature differences are now negative and $C_n^2$ increases. Atmospheric convection attempts to rebalance the unstable conditions by mixing the near surface warm air into the cooler air aloft. The persistent sun strengthens the unstable state, deepening the mixed layer. The constant mixing intensifies the atmospheric density variations and the AOT further increases. AOT reaches a peak around midday, or soon after.

The waning of the sun in the clear afternoon skies reduces the insolation and decreases the negative Delta-T magnitudes. Subsequently, AOT decreases. Just prior to sunset, the atmosphere briefly becomes near-dry adiabatic (neutral) and $C_n^2$ drops to a minimum. The heat flux goes to zero and the day's second NE takes place.

*Sunset occurs.* Civil, Military and Astronomical Twilights quickly evolve until there is the nighttime darkness. The previously warmed soil strongly emits the Solar Radiation absorbed during the daylight hours and cools rapidly. Delta-T becomes positive, confirming the presence of a stable atmosphere. Colder, heavier air, from the surrounding mountains and hills, drains into the valleys, serving as a mixing tool. The non-uniform radiative cooling and clear sky drainage flow creates an ambient mixing, which keeps the AOT at a moderate level throughout the night. The moderate AOT is punctuated by occasional, intermittent AOT maxima.

Within the diurnal cycle just described, the two primary NE times are clearly linked with the local sunrise and sunset. As the stable nighttime conditions transition to unstable daytime conditions, a Sunrise NE occurs. Likewise, as the unstable daytime evolves to a stable nighttime atmosphere, a Sunset NE occurs. Common to both scenarios is a period in which the atmosphere is near-dry adiabatic, exhibiting the least variations of $C_n^2$ along a horizontal and vertical path. The target of the SLST research is to successfully forecast the initial time for these transition events (Vaucher et al., 2003).

### 1.6 Ideal and Non-ideal Stability Transition Forecast Standards

Two distinct scenarios, Ideal and Non-ideal atmospheric conditions, were observed during the mid-1990 ST studies:

1. Ideal atmospheric conditions were defined as clear skies, low winds and low ground moisture.

2. Non-ideal atmospheric conditions included all other atmospheric traits, especially any cloud occultation of the sun during sunrise/sunset.

Local atmospheric conditions determined the ST duration. Under Ideal conditions, the transition was often less than 2 min. Ironically, the Ideal condition ST forecast (with seasonal correction algorithms) produced the best results for the HELSTF, WSMR, NM site. In fact, one could accurately forecast to the minute when a Sunrise NE would occur 9 months in advance of the forecast, presuming that the day of validation had Ideal atmospheric conditions.

Forecasting for the Non-ideal atmospheric scenario was another story. First, the NE duration was anywhere from 1 min to over 20 min In the 2001 June Solstice-Atmospheric Surface Layer Test, a nighttime NE existed for over 20 min. Another characteristic of Non-ideal scenarios was the generation of multiple NEs. Some major contributors to these Non-ideal NE conditions included:

1. Solar disc occultation during sunrise/sunset.
2. Sun ray obscuration after sunrise/before sunset.
3. The presence of local ground moisture.
4. The presence of non-standard local forcing (such as a frontal passage).

## 2. Statistical Minimum In Seasonal Algorithm

### 2.1 2001 September Equinox-Atmospheric Surface Layer Test Overview

The 2001 September Equinox-Atmospheric Surface Layer Test was executed in three phases: two Pre-Tests (5–7 and 18 September), and the actual Test (19–21 September). The test site used was the 100 ft Thompson Tower site (Lat: 32.35, Long: –106.47), in WSMR, NM, with a scintillometer path extending about 1 km west-southwest to Ammo Site. The participants of the Test included MIT and David Tofsted of ARL's Weather Exploitation Branch, who provided support for the $C_n^2$ equipment. The Test Coordinator/Director was Gail Vaucher. Acting Test Director for 28 August to 14 September was Scott Elliott. The Test Schedule was designed around mission and travel requirements. The four objectives of the Test, with their point-of-contacts (POC), were:

1. To be the third of three FY 2001 sampling sets aimed at verifying the maximum and minimum magnitudes of the Neutral Event Forecasting Model seasonal effects (POC: Gail Vaucher).
2. To quantitatively characterize the desert atmospheric Surface Layer by studying the atmospheric thermodynamics and Surface Layer advection during the night-to-day transition period (POC: Doyle "Scott" Elliott).
3. To characterize atmospheric transition events aloft, via the Wind Profiling Radar (POC: Edward Creegan).
4. To obtain high data rate $C_n^2$ measurements over a 950 m path (POC: David Tofsted).

Prior to the field test execution, the Thompson Tower site 4 m scintillometer scaffolding tower was moved to the Ammo Site. A single, 5 m meteorological tower replaced this scaffolding at Thompson Tower. Elevated cabling posts were used at Ammo Site and Thompson Tower to prevent future damage to the cables caused by local wildlife (which had damaged previous cabling). The temporary housing for the computer equipment at the remote Ammo Site was provided by a Commercial Utility Cargo Vehicle with shelter. The power for the site was a mobile 20 kW generator. A mobile High Speed Trailer (HST) attached to hard power provided the equivalent at the Thompson Tower site. The versatile HST served as a Post-test data processing center and Testers' Conference Room.

Meteorological sensors included a 4 m TacMet II Unit, and a 10 m 3-level tower of 3D Sonic Anemometers at the Ammo Site. A Campbell Data Logger linked two Thompson Tower surface sensor units (2 m and ~ 38 m levels). Vaisala global positioning system (GPS) rawinsondes were launched from a High Mobility Multi-Wheeled Vehicle (HMMWV) situated west of Thompson Tower. The HMMWV also served as the housing for the 924 MHz Wind Profiling Radar. The Radar Antenna was placed west of Thompson Tower and slightly southwest of the HMMWV. A 25 kW Quiet Generator powered the HMMWV. The HST was placed north and slightly west of Thompson Tower, and used hard power. Figure 5 shows the Field Test Structures and Sensors Layout.

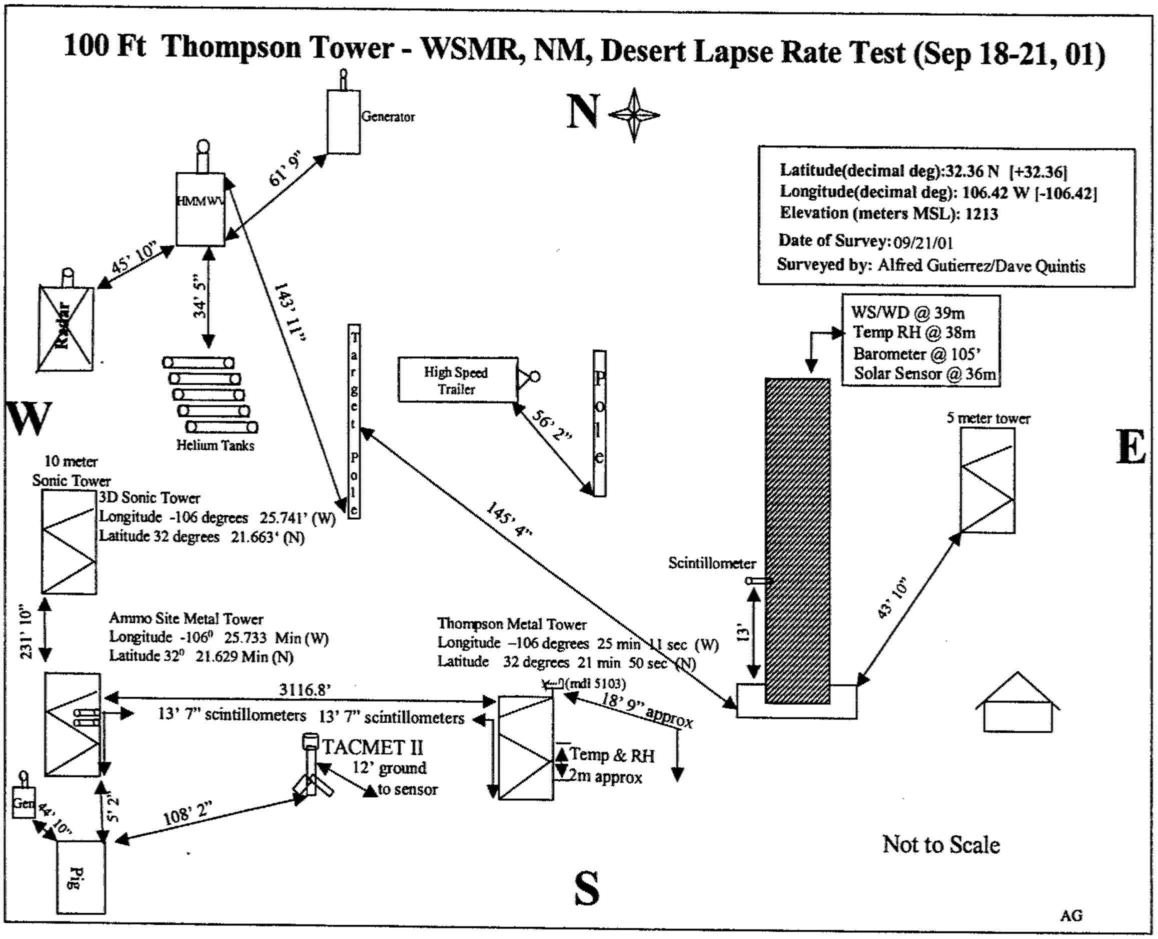


Figure 5. Field Test Structures and Sensors Layout.

A Pre-Test equipment and acquisition capability check was conducted 5–7 and 18 September 2001. Thompson Tower meteorological sensors, Radar, and RAOB systems successfully ran simultaneously. The Sonic and Scintillometer equipment were installed and aligned prior to the Test. These latter systems were under development, therefore, each unit was employed as the system became functional. Thompson Tower and the Ammo Site tower data were deemed acceptable during the Pre-Tests.

## 2.2 Test Execution

Test Days 1–3 (2001 Sep 19–21) began at 0400 Mountain Daylight Time (MDT), with all participants traveling to the 100 Ft Thompson Tower in a caravan. This strategy served to minimize desert dust around the field site. There were three data acquisition cases scheduled per day. These cases characterized the nighttime desert atmosphere (0500–0700 MDT), the onsite ST/NE (0700–0900 MDT), and the daytime desert atmosphere (0900–1100 MDT). Due to an imposed administrative restriction on work hours, this latter case had to be shortened. After each test day, all data were plotted, reviewed and discussed by the six onsite participants (Vaucher, 2001).

A morning WSMR mission coincided with Test Day 3. Working cooperatively with the WSMR Met Team, ALL RAOB launches were released on schedule at the Thompson Tower site. The Thompson Tower data for all cases ran uninterrupted. A Team member, working normal business hours on the WSMR Post provided daily synoptic weather charts and administrative information. Cell phones and radios helped maintain communications and safety between sites.

### 2.3 Test Results

This section begins with a General Weather Overview, followed by a brief characterization of the Nighttime (Stable), Transition (NE), and Daytime (Unstable) Sub-cases. Finally, unique features of the three observed NEs are described.

#### 2.3.1 General Weather Overview

Throughout the three-day Experiment, an upper-level High was centered over Northern Mexico. The WSMR rawinsondes reported that the site was under the High's westerly flow. Weak disturbances drifted around the upper High, bringing some moisture with them. Local skies ranged from mostly sunny to partly cloudy. Though there was not enough moisture for a monsoon thunderstorm build-up, some morning ground moisture was observed (Forecast for White Sands Missile Range, Intellicast.com, Real-Time Weather Data, 2001).

#### 2.3.2 Characterization of Nighttime, Transition, and Daytime Atmospheric Conditions

Atmospheric conditions for Day 1 were near Ideal: clear skies, low winds, and some ground moisture. Day 2 was characterized as Non-ideal: morning clouds obscured the sunrise causing multiple and extended STs. Day 3 was both Ideal and Non-ideal: the immediate eastern horizon was initially clear of clouds, but soon after the solar disc rose, clouds filtered the warming rays. Winds were light, and ground moisture was observed (dew on the Radar Radome).

*Nighttime (0500–0700 MDT).* Pressure (P) increased slightly (less than +1.5 mb). Characteristically cool temperatures were sampled near the surface, generating a Delta-T range of +2 to +7 °C. Relative Humidity (RH) was 20–50 percent, with 2 m RH greater than the 38 m RH. Winds were less than 5 m/s, with generally divergent magnitudes between the 5 and 39 m sampling heights. Wind directions (WD) were also divergent, with the lowest surface winds primarily from the northern quadrants.

*Transition (0700–0900 MDT).* The P continued to increase with time (+1 to +1.4 mb). Delta-T began with a Stable +4 °C (2 m < 38 m). After the transition (NE), Delta-T was approximately 2 °C (Unstable). The greatest Delta-T change generally occurred minutes before the first ST (between 0741–0750 MDT). The RH began with an upper verses lower RH differential of 20–40% (greatest RH at 2 m). Then, like Temperature (T), the independent RH sensors reported a transition in the humidity. The post-transition RH difference was less than 5%, with the dryer conditions generally at 2 m. Wind speeds (WS) between the 5 and 39 m levels were less than 5.5 m/s. While the upper and lower levels began as pseudo-independent airflow, the magnitudes appeared to converge at the time of transition. This convergence was noted in the 2001 June Case Study. The unified condition persisted throughout the end of this case. Intermittent cloud cover was quantified by independently observed "Percentage of Sun" disc occultation, as seen through a Welder's Glass.

*Daytime (0900–1100 MDT).* The smallest P increases occurred during this time period (+0.4 to +0.5 mb). The Delta-T consistently hovered between –1.2 and –1.9 °C, with the warmest T at 2 m (Unstable). The RH differences (2 and 38 m) were less than 5%. The WS was < 4.5 m/s, with both tower levels reporting a relatively unified direction. Cloud obscuration was generally less over this time period.

### 2.3.3 Observed Unique Features of the Three Stability Transitions

All three STs occurred within the forecasted times. That is, the forecasted time plus or minus the standard deviation for September.

*Day 1(19 September).* The clear morning skies yielded a single, 4-min, uninterrupted ST. Ground moisture, in the form of dew, was observed on the radar's antenna.

*Day 2(20 September).* The Non-ideal conditions (beginning with clouds obscuring the sunrise) created multiple and extended STs. Despite the occulted sunrise, the first of these transitions occurred at the forecasted time. Based on Delta-T magnitudes, the second transition extended for about 18 min. Graphically, this event might be interpreted as two events. The final transition occurred shortly after, and consumed the least amount of time. Dew was evident during this test day.

*Day 3(21 September).* Day 3 presented both Ideal and Non-ideal conditions. Clear skies were observed before and after the sunrise. During sunrise, there were non-occulting clouds reported along the eastern horizon, and local ground moisture (Non-ideal) noted. A brief solar disc cloud obscuration was observed just prior to the ST. It is interesting to note that the single observed NE occurred prior to the forecasted time, but within the forecasted standard deviation for September.

## 3. Discussion Of Results

For this discussion, the analysis is narrowed to each Day's actual NE. Placing the NE in the center and allowing a buffer of 30 min before and after the center point, we now re-examine the attributes of the atmosphere surrounding the morning transition(s) and contrast them with the previous 2001 Field Experiments.

Multiple and extended STs were reported in the 2001 June Case Study Technical Report (Vaucher and Bustillos, 2003). This September study also documents multiple and extended transitions. Unlike the June Study, however, all NEs occurred after sunrise and.were initiated within the standard deviation of the forecasted NE. Unlike June, local forcing came in a much more subtle manner, namely no fronts or local thunderstorms were observed in the Test area. Instead, the primary suspects for generating these multiple and extended events included the expected solar disc obscuration by clouds, as well as the ground moisture observed as local dew. With this in mind, we again review each Day's NE.

Day 1 displayed an extended (4 min) NE. Winds at the 2 m and 39 m levels were all less than 2 m/s, confirming a lack of local dynamic forcing. The highest 2 m RH was measured soon after local sunrise (approximately 96%). The coincident and significantly dryer 38 m RH implied an independent air mass aloft. As the NE approached, the 2 m RH dropped to about 70%. The 38 m RH dried less than 10 percent. Within 10 minutes after the transition, the lower and upper air masses completed their initial homogenizing mixing, with the 2 m RH showing a slightly dryer value than the 38 m RH. Due to the lack of cloud cover, the only explanation for the slightly extended transition would be that the ground moisture "damped" the rate of change in the surface heat flux. The fact that the surface RH remained slightly dryer than above indicates that the ground moisture's impact on the atmosphere was quickly overcome by the full solar heating under clear skies.

Day 3 reported the more typical NE (2 min). On this day, the highest 2 m RH occurred just after sunrise (around 75%). The 38 m RH paralleled Day 1, in that it showed a much dryer air mass aloft. However, unlike Day 1, there is no same-direction drying trend between these two layers. Instead, while the lower layer slowly dries, the upper air mass gains moisture. This upward moisture flux continues until the two layers report their first mutual RH value (~ 65%), which also coincides with the morning NE.

Why did the NE occur on the late side of the forecasted value for Day 1 and the early side for Day 3? One possible answer rests in the moisture factor. Ground moisture was observed on both days. Distinguishing the two cases is that the 38 m level acted as a sponge on Day 3. Perhaps the liberal upward mixing of moisture allowed the local environment to transition early. Whereas on Day 1, the moisture was not so easily upward-mixed, and thereby served as a retarding agent in the process of transitioning.

Day 2 presents multiple (three) STs. The durations of the STs, in chronological order, were 6, 18 and 2 minutes. These times were determined from the empirical Delta-T bounds defined in the 2001 June Case Study, namely +/–0.25 °C. At sunrise, the 2 m and 38 m levels appeared to be independent air masses: winds aloft were about 2–3 m/s faster than at the surface, 2 m RH was around 65%, and 38 m RH was around 45%. At the first NE, which coincided with the forecasted NE, the 2 m RH had only dried to 58%. By the end of the last ST, the 2 m RH was 55%. Little variation was reported between these points. Though one would expect mixing to bring the upper and lower RH values together, the lower layer rose only about 5%. Even during the final NE, the RH values are separated by about 3%, with the 2 m RH being the moister. Winds at both levels were 3 m/s and less. The WD aloft was southeasterly and northeasterly at the surface. Occulting cloud cover persisted throughout the 3 transitions.

Kunkel and Walters stated that refractive index fluctuations ($C_n^2$) were caused primarily by fluctuations in temperature, and to a lesser extent by fluctuations in water vapor pressure (1983). After reviewing the data from these three Field Experiments, we need to add our empirical understanding to their model observations. That is, while multiple and extended STs are a function of reduced insolation (clouds occulting the sun) and ground moisture, the multiple STs appear to correlate more strongly with reduced insolation. Extended NEs appear to be associated with abundant local ground moisture.

## 4. Summary and Conclusions

The defining objective for the three FY01 field tests was to verify and validate the seasonal impact on the near-surface STs (NEs). With limited personnel or hardware resources, we were only able to address the maximum and minimum points on the seasonal curve discovered by Vaucher and Endlich (1995). In the 2001 March Equinox-Atmospheric Surface Layer (ASL) Test, we were encouraged when ideal atmospheric conditions yielded strong agreement with the forecasted event (Vaucher et al., 2003). The 2001 June Solstice-ASL Test educated us in the effects of Non-ideal conditions. Data that quantified (versus qualified) the multiple and extended STs was acquired and analyzed (Vaucher and Bustillos, 2003). Finally, in the 2001 September Equinox-ASL Test, we observed both Ideal and Non-ideal atmospheric conditions. The true character of these two scenarios was examined, and two repeatable Non-ideal condition attributes were added to our understanding. Does this conclusively mean that the seasonal algorithm is verified? Yes and no. Under Ideal conditions, the model was successful. Under Non-ideal conditions, the model was not successful in the 2001 June Case Study, but was successful in the 2001 September Case Study. If we extend this to the other questions posed in Section 1.4, we have evidence that the seasonal algorithm is not unique to just the original desert data site. We also have quantitative proof that (1) these STs can occur multiple times during the day AND night, (2) transition conditions can continue for at least 26 min, (3) ground moisture is a significant factor in generating Extended STs and (4) reduced insolation (solar disc occultation by clouds) tends to yield Multiple STs. Finally, these three field tests have produced 9 case studies that quantitatively characterize the desert-atmospheric Surface Layer's night, transition and daytime conditions.

What's next? The Boundary Layer Exploitation Task objective prompting these field tests was "to identify, characterize, model and exploit repeatable patterns within the Atmospheric Surface Layer that are useful to the military" (Vaucher, 2001). These tests have indeed identified the repeatable atmospheric Surface Layer ST pattern. The data has quantitatively added to the characterization of the transition pattern, as well as validated the Ideal Scenario parts of the ST Forecast Model. As we look toward the model-improvement phase of the objective, we also need to re-examine the exploitable attributes of this atmospheric research. U.S. Army Secretary Chief of Staff Shinseki's 2002 vision was "to see first". With this research, we have expanded his vision to, "to see better." Linking this work with military EO propagation missions, such as reconnaissance/surveillance, IR sensors/weapons effectiveness and HEL laser weapon systems, is just one area of exploitation. Other uses for a ST Forecast Model would be as an information module in the larger military simulation and strategy models. Finally, ST Forecast Models also have their niche as critical input modules (initializing point(s)) for atmospheric chemical and biological weapon distribution/dispersion models that are based on the atmospheric convective processes.

## Acronyms

| | |
|---|---|
| AOT | Atmospheric Optical Turbulence |
| AGL | Above Ground Level |
| ARL | Army Research Laboratory |
| $C_n^2$ | Index of Refraction Structure Function |
| Delta-T | Temperature Difference $[T_{38m} - T_{2m}]$ |
| ELR | Environmental Lapse Rate |
| EO | Electro-Optical |
| FY | Fiscal Year |
| GPS | Global Positioning System |
| HEL | High Energy Laser |
| HELSTF | High Energy Laser Systems Test Facility |
| HMMWV | High Mobility Multi-wheeled Vehicle |
| HST | High Speed Trailer |
| IR | Infrared |
| MIT | Meteorological-sensors Integration Team |
| MDT | Mountain Daylight Time |
| MM5 | Pennsylvania State University/National Center for Atmospheric Research Mesoscale Model version 5 |
| NE | Neutral Event |
| P | Pressure |
| POC | Point of Contact |
| RAOB | Rawinsonde Observation System |
| RH | Relative Humidity |
| SLST | Surface Layer Stability Transition |
| SR | Solar Radiation |

| | |
|---|---|
| SRNE | Sunrise Neutral Event |
| ST | Stability Transition |
| T | Temperature |
| WS | Wind Speed |
| WSMR | White Sands Missile Range |
| WD | Wind Direction |

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# Appendix A: Thompson Tower Data

This appendix is part of ARL-TR-2827, Surface Layer Stability Transition Research Minimum Neutral Event-to-Sunrise Time Interval: 2001 September Case Study, U.S. Army Research Laboratory, White Sands Missile Range, NM 88002-5501.

A Eulerian (fixed point) perspective on the atmospheric conditions during the Nighttime (Stable) to Daytime (Unstable) transition was quantitatively recorded by the Thompson Tower data. Thermodynamic time-series data was acquired at the 2 m and 38 m above ground levels (AGL). Wind data were acquired at 5 m and 39 m AGL. For convenience, we have designated data representing the lower layer with a brown box and the upper layer with a blue open circle. Efficiency has dictated that all three Sub-cases (Stable, Neutral, Unstable) be presented in a single time-series plot. Approximate times for each Sub-case were:

| | |
|---|---|
| Stable | 0500–0600 MDT |
| Neutral | 0700–0900 MDT |
| Unstable | 0900–1100 MDT |

The 2001 September 18 Pre-Test data were included for completeness. The following are the four sections of Appendix A:

- Figures A1–A7: 2001 September 18
- Figures A8–A14: 2001 September 19
- Figures A15–A21: 2001 September 20
- Figures A22–A28: 2001 September 21

**Figures A1–A7: 2001 September 18-Thompson Tower Data**

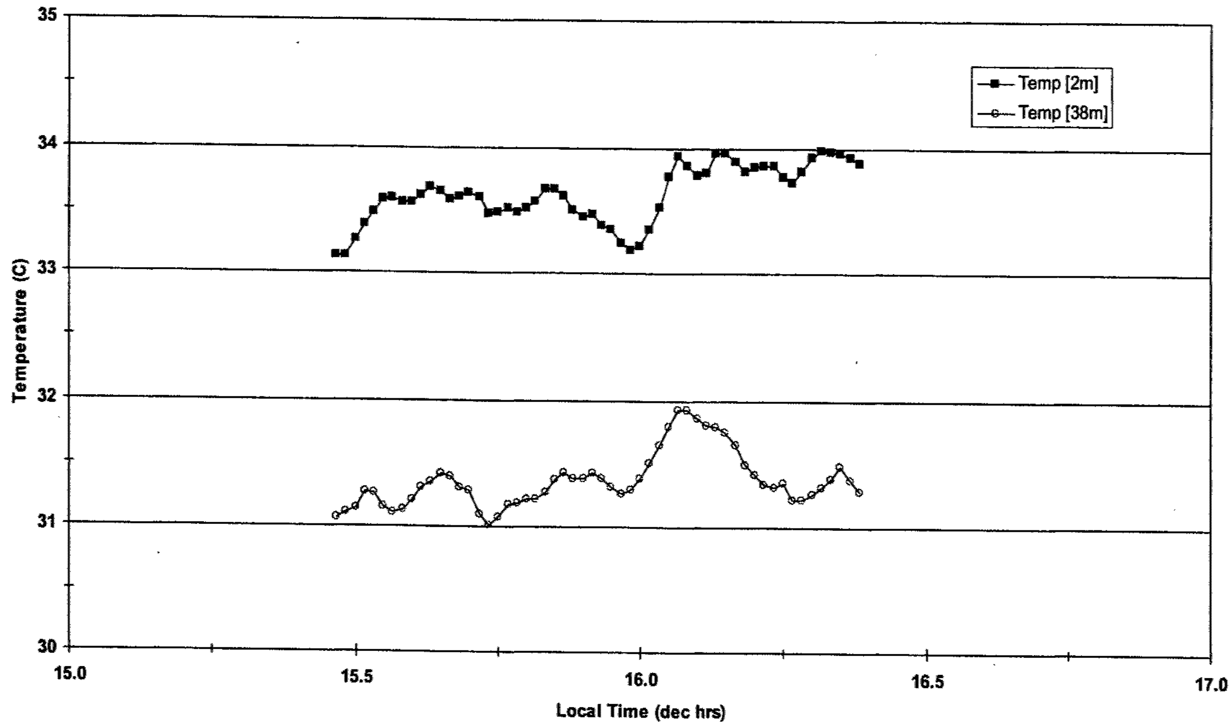



Figure A1. Thompson Tower-2001 September 18: Temperature.

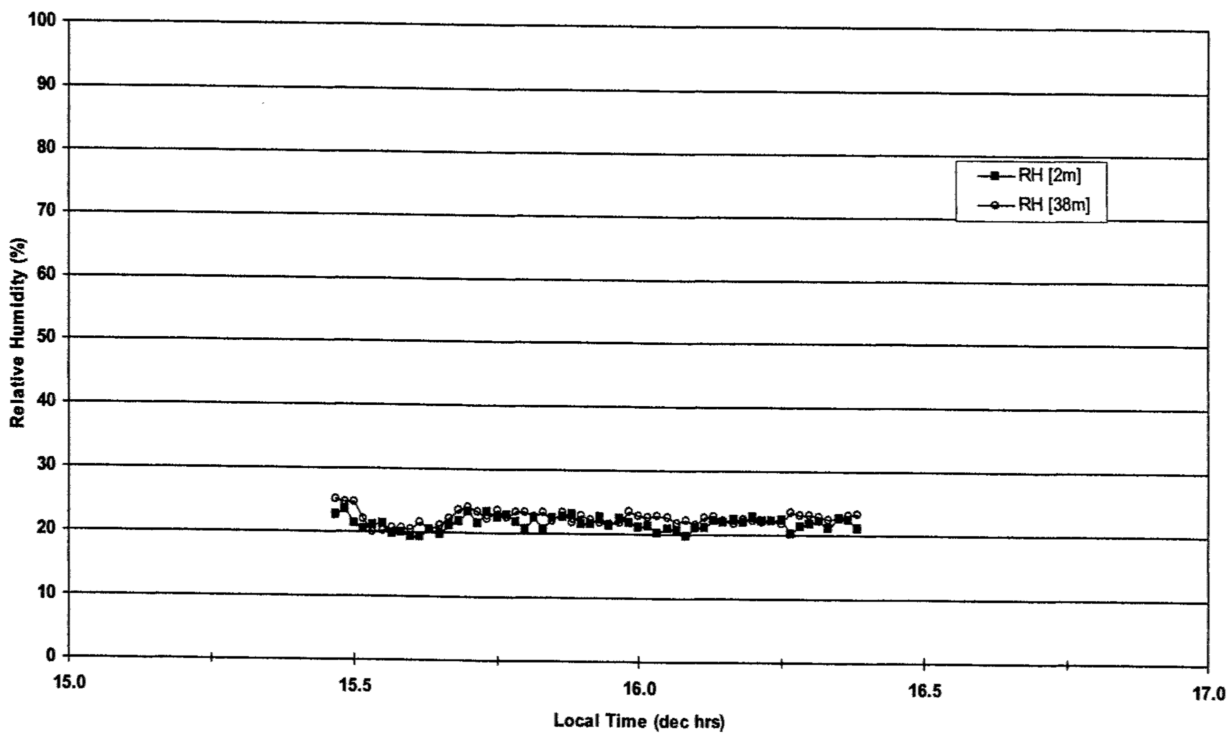



Figure A2. Thompson Tower-2001 September 18: Relative Humidity.

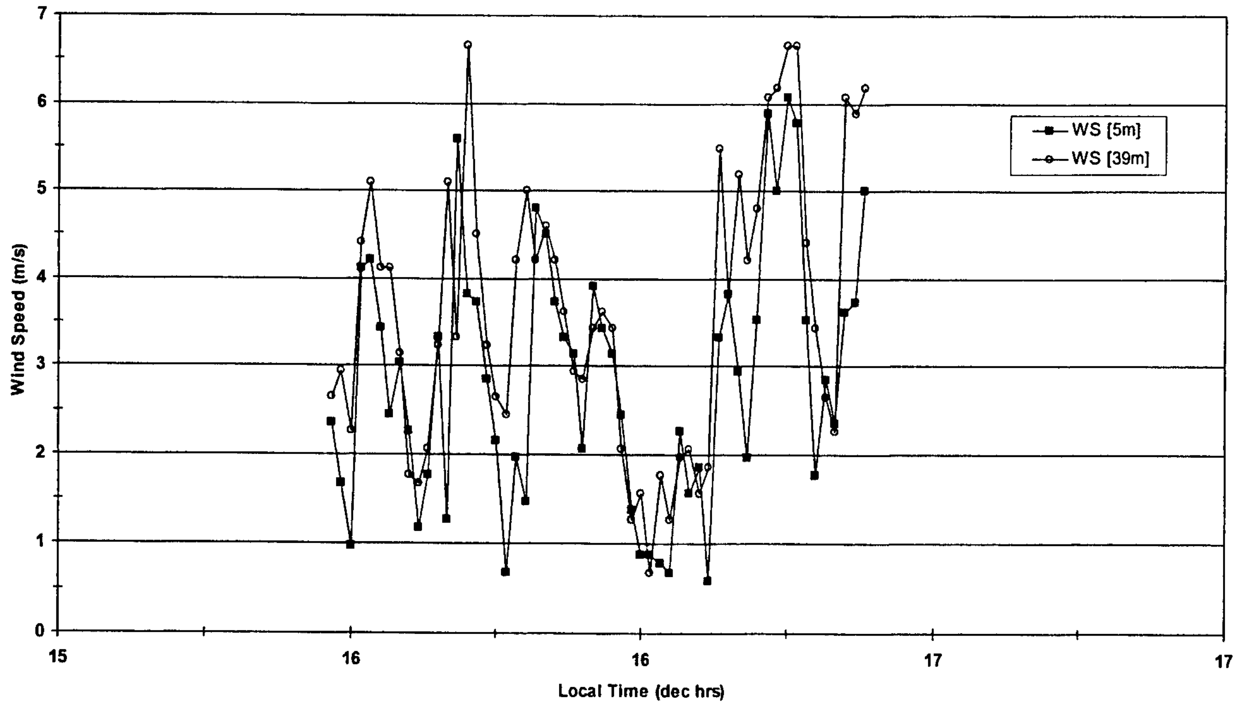



**Figure A3. Thompson Tower-2001 September 18: Wind Speed.**

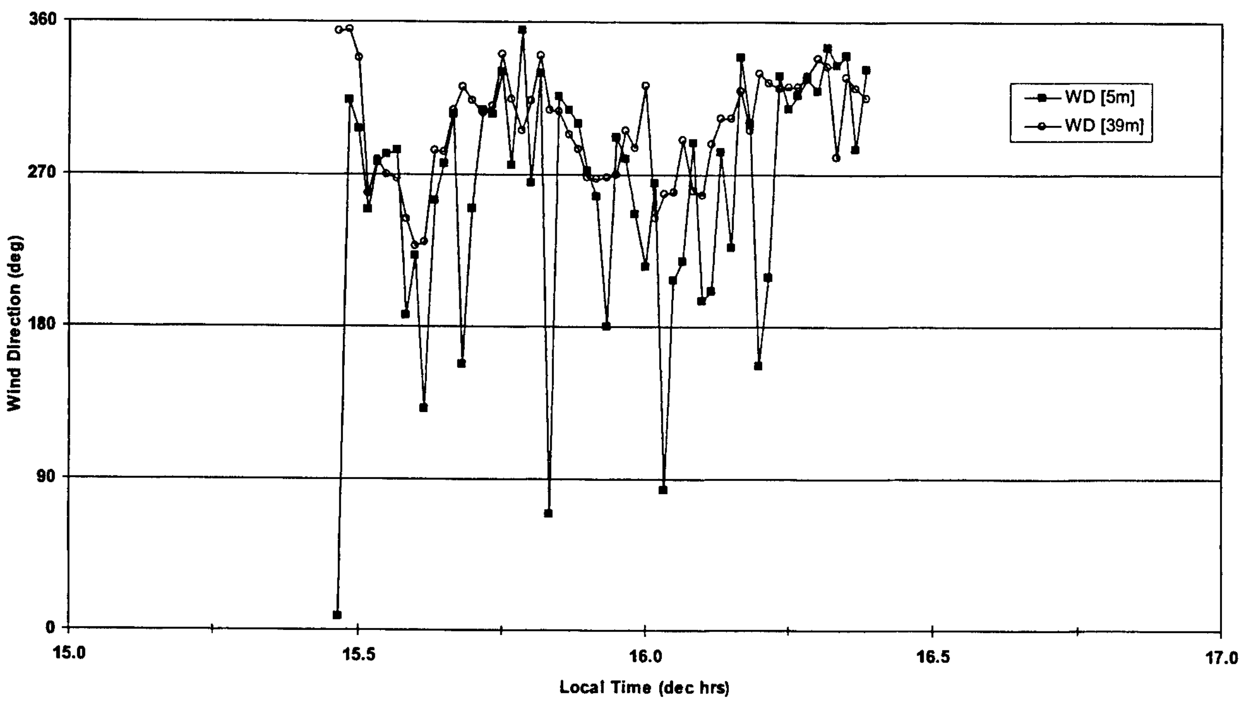



**Figure A4. Thompson Tower-2001 September 18: Wind Direction.**

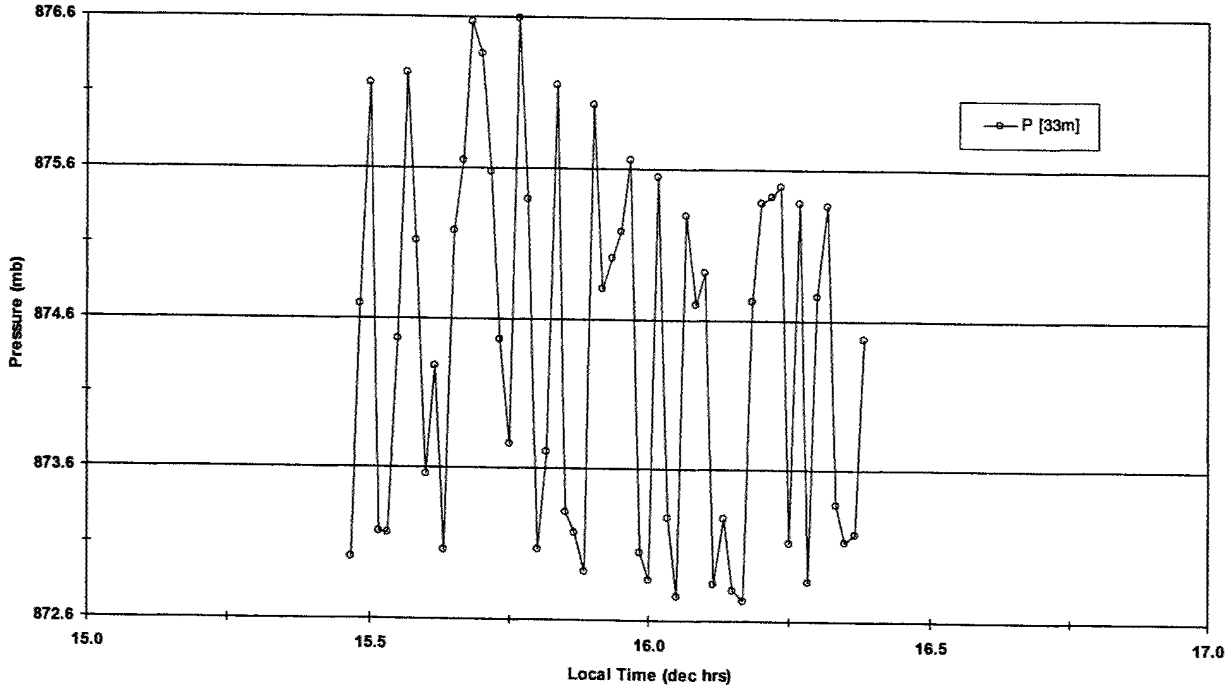



**Figure A5. Thompson Tower-2001 September 18: Pressure.**

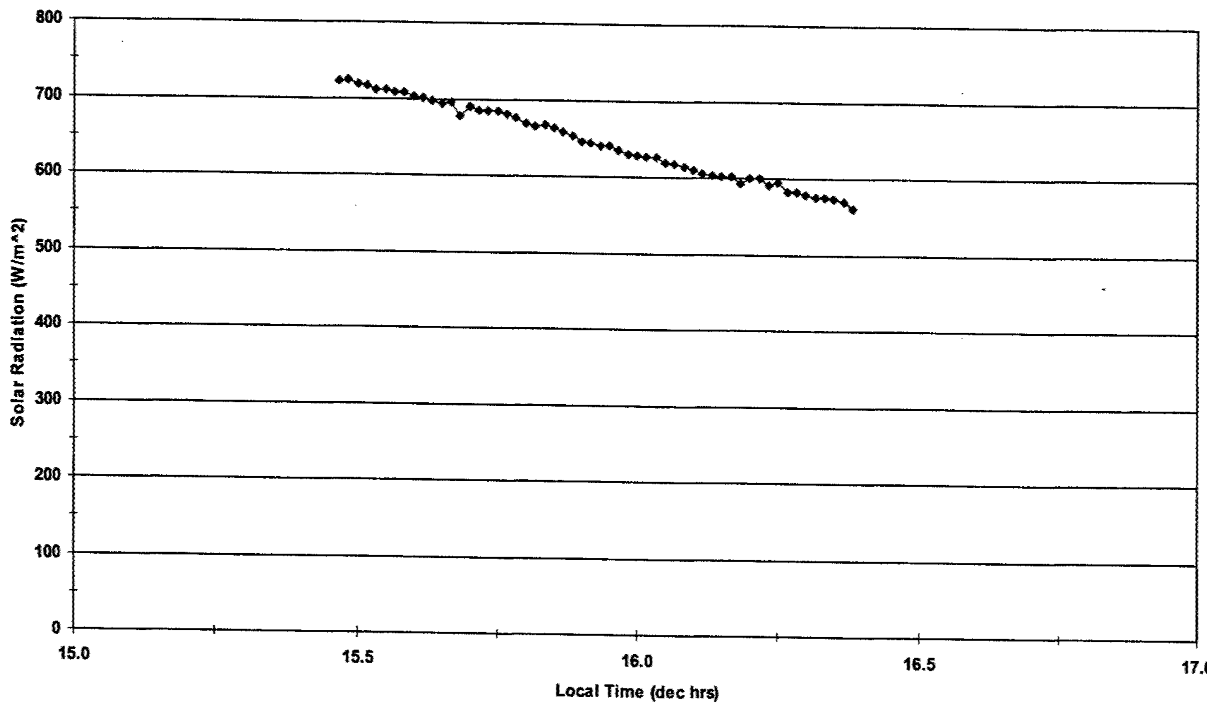



**Figure A6. Thompson Tower-2001 September 18: Solar Radiation.**

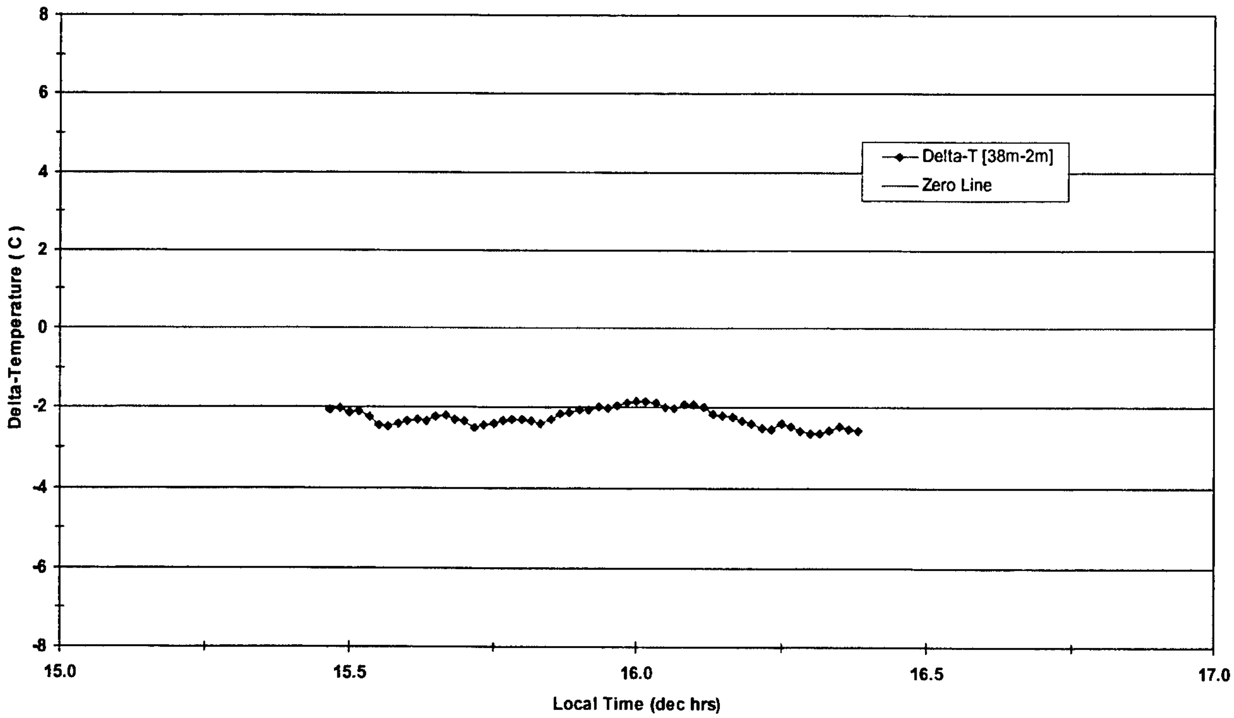



**Figure A7. Thompson Tower-2001 September 18: Delta-T.**

**Figures A8–A14: 2001 September 19-Thompson Tower Data**

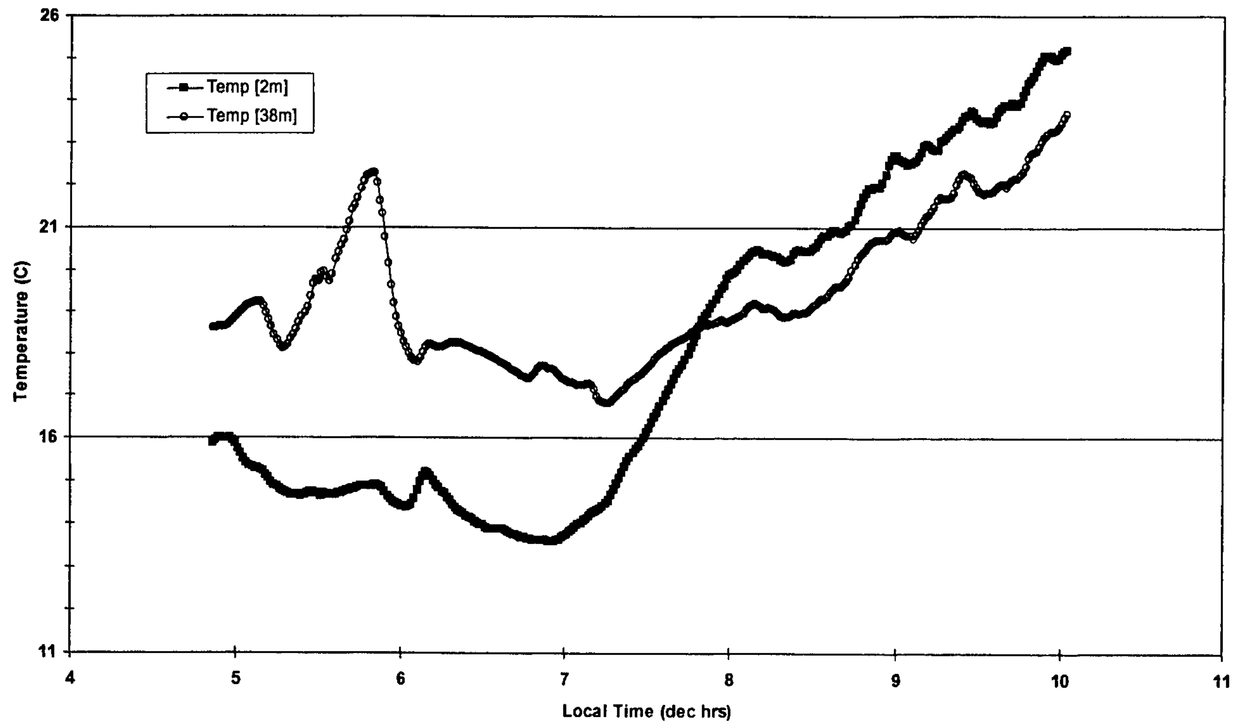



**Figure A8. Thompson Tower-2001 September 19: Temperature.**

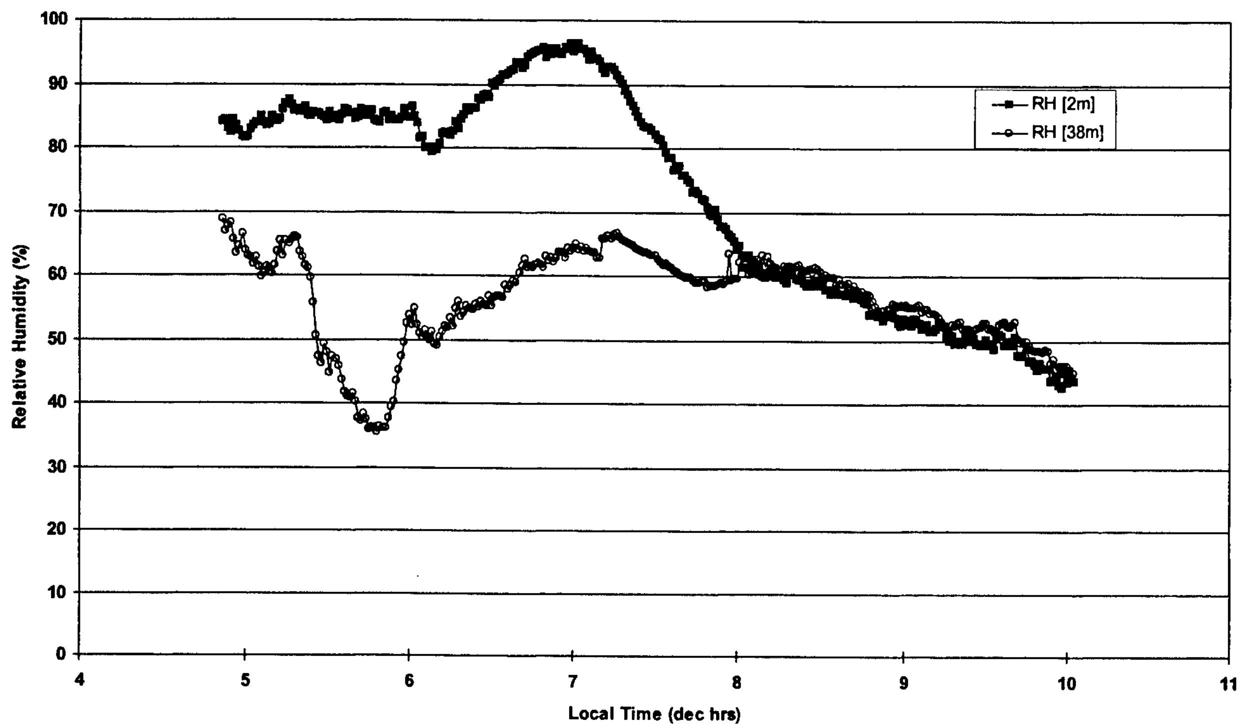



**Figure A9. Thompson Tower-2001 September 19: Relative Humidity.**

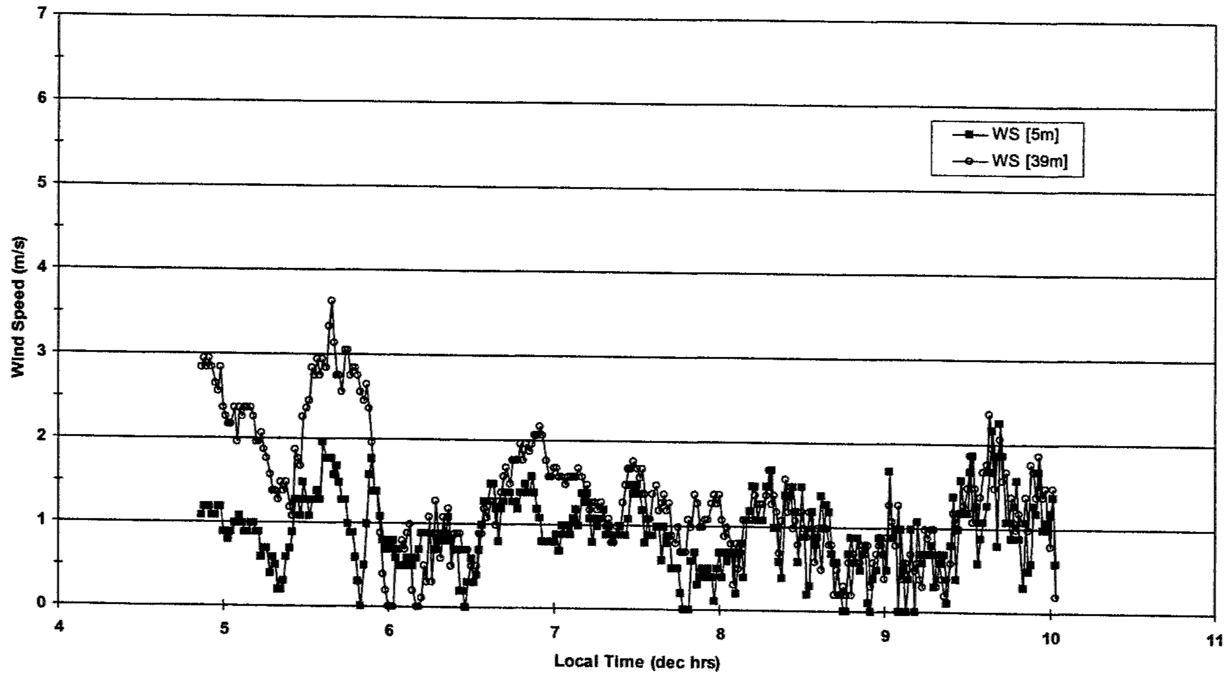
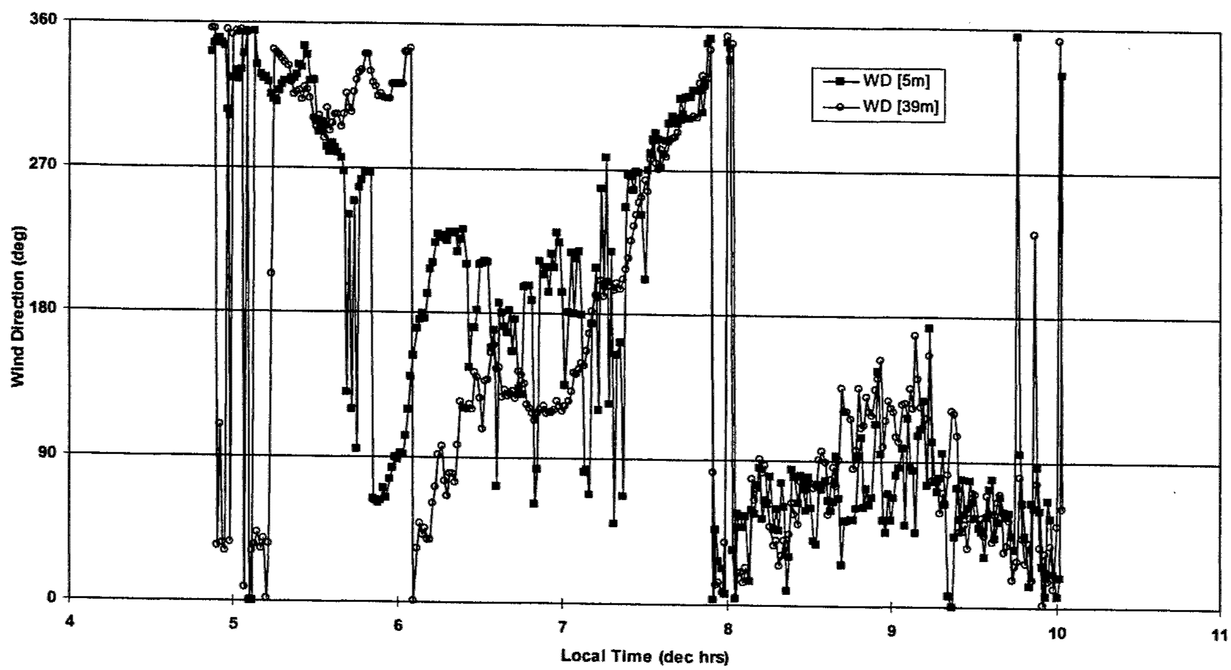



**Figure A10. Thompson Tower-2001 September 19: Wind Speed.**




**Figures A11: Thompson Tower-2001 September 19-Wind Direction.**

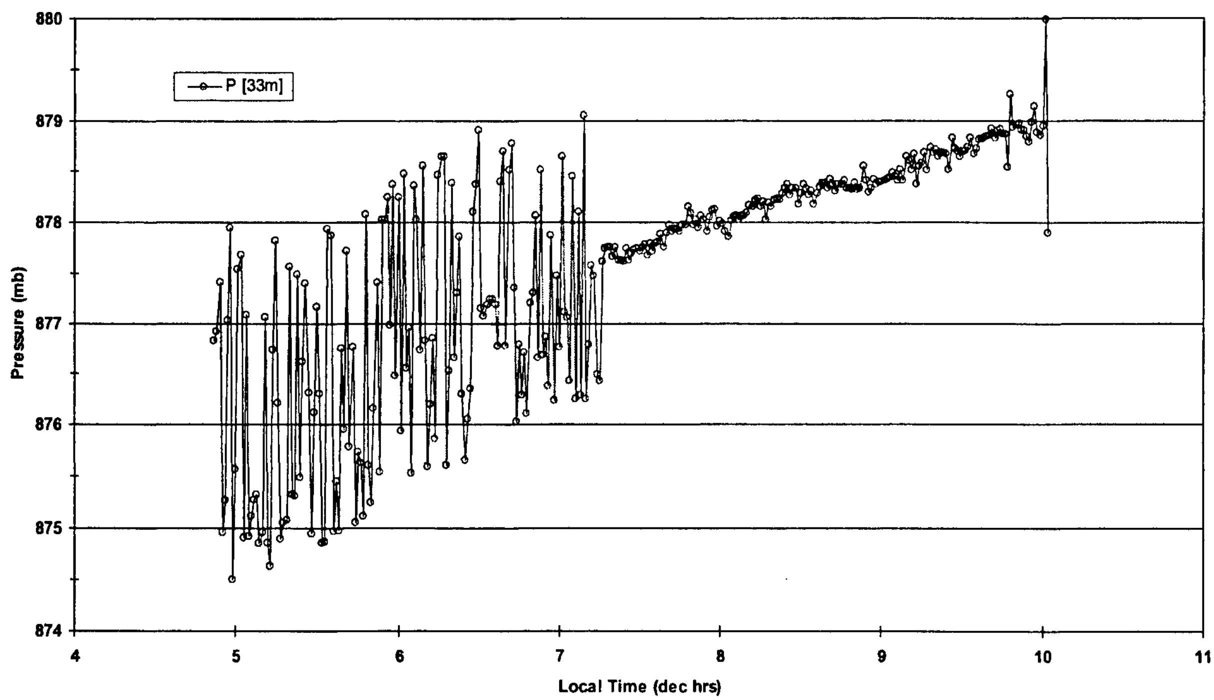



**Figure A12. Thompson Tower-2001 September 19: Pressure.**

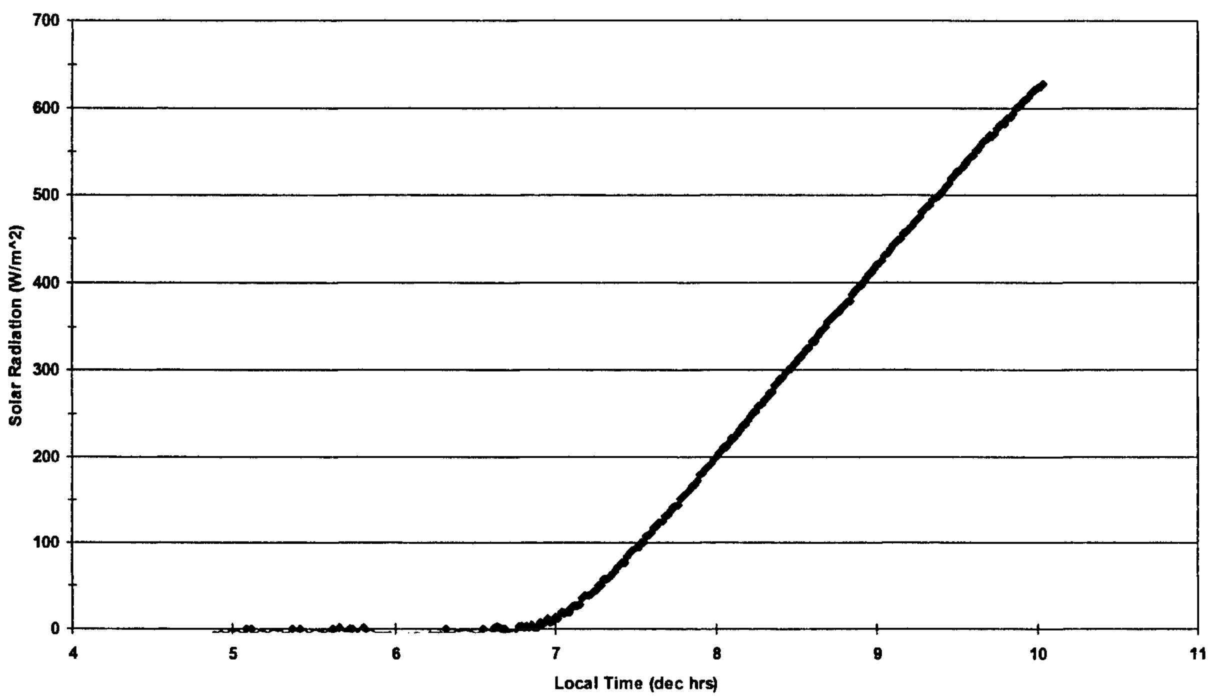



**Figure A13. Thompson Tower-2001 September 19: Solar Radiation.**

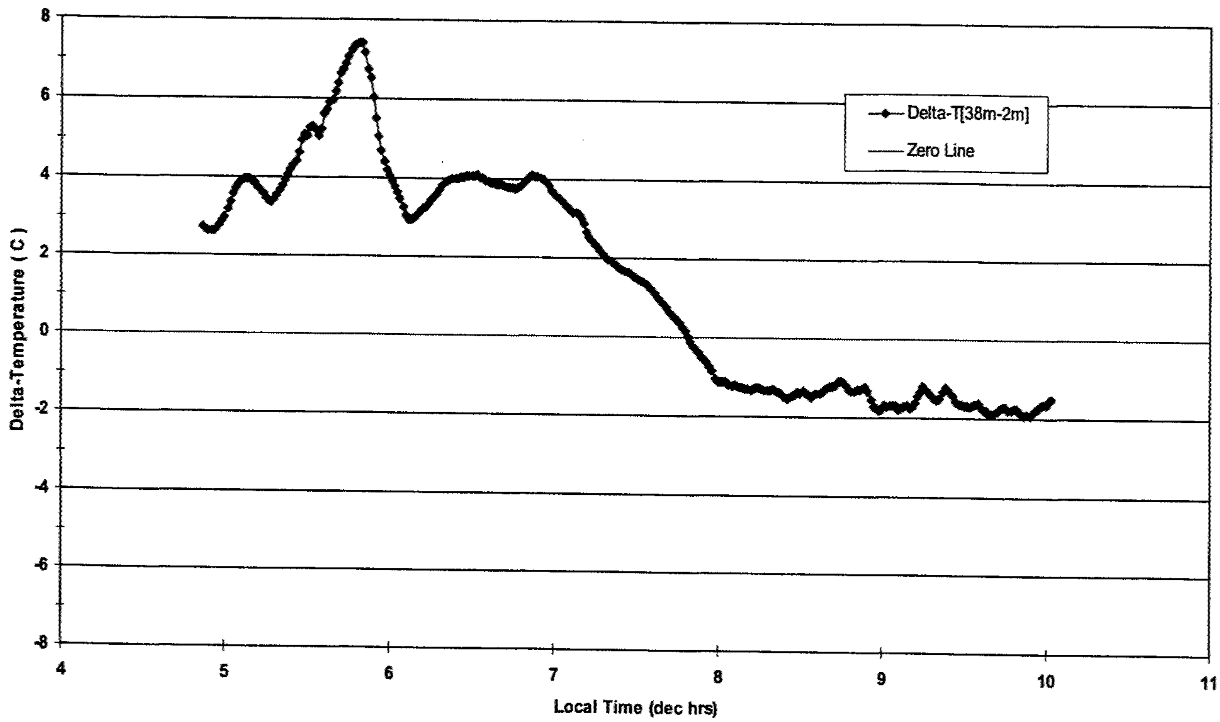



**Figure A14. Thompson Tower-2001 September 19: Delta-T.**

**Figures A15–A21: 2001 September 20-Thompson Tower Data**

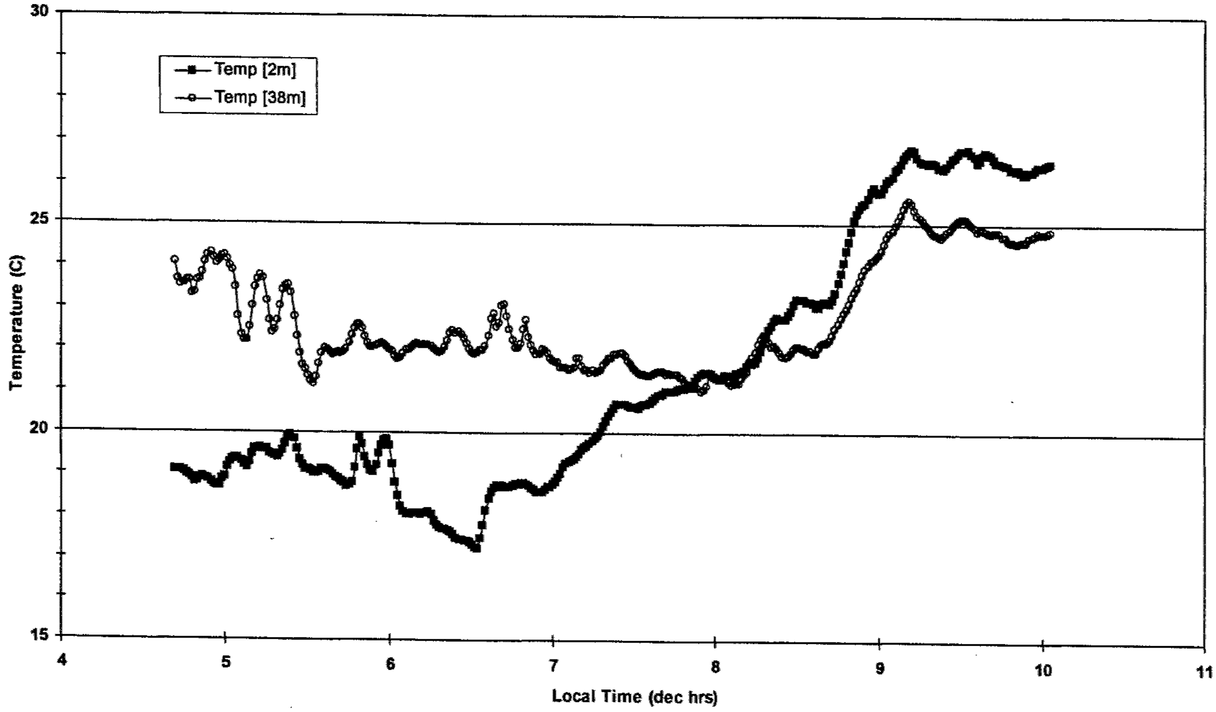



**Figure A15. Thompson Tower-2001 September 20: Temperature.**

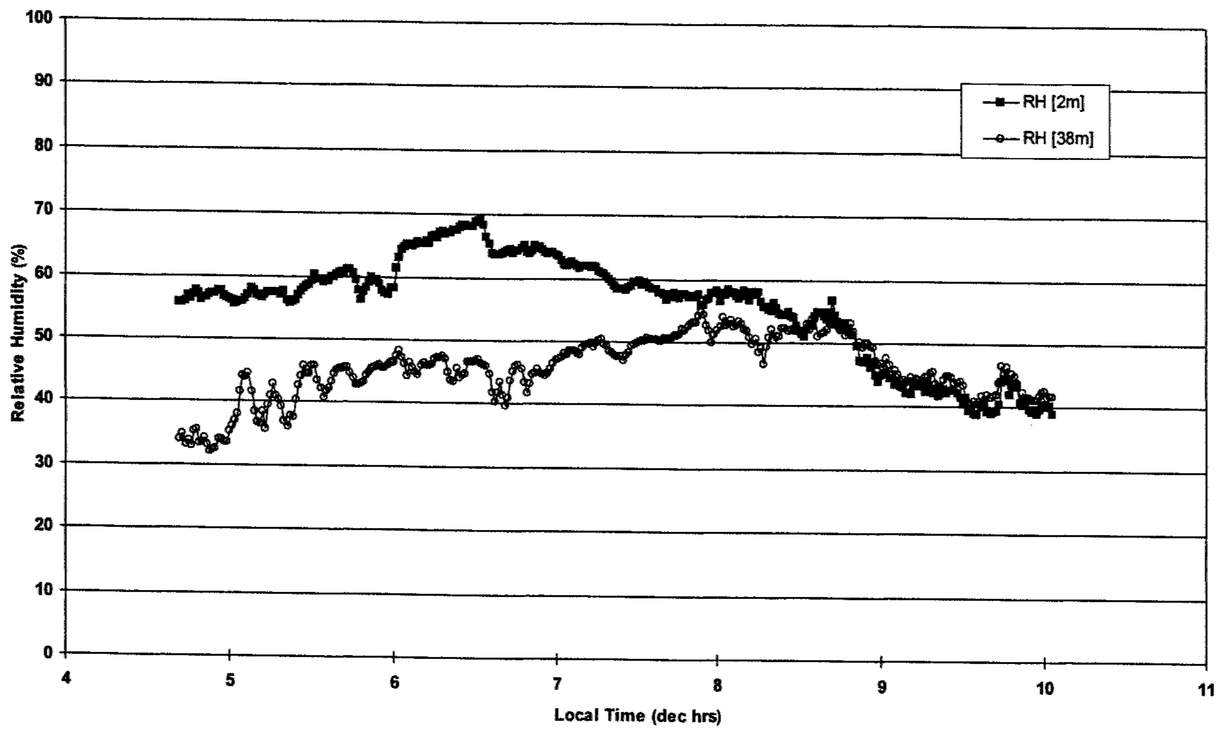



**Figure A16. Thompson Tower-2001 September 20: Relative Humidity.**

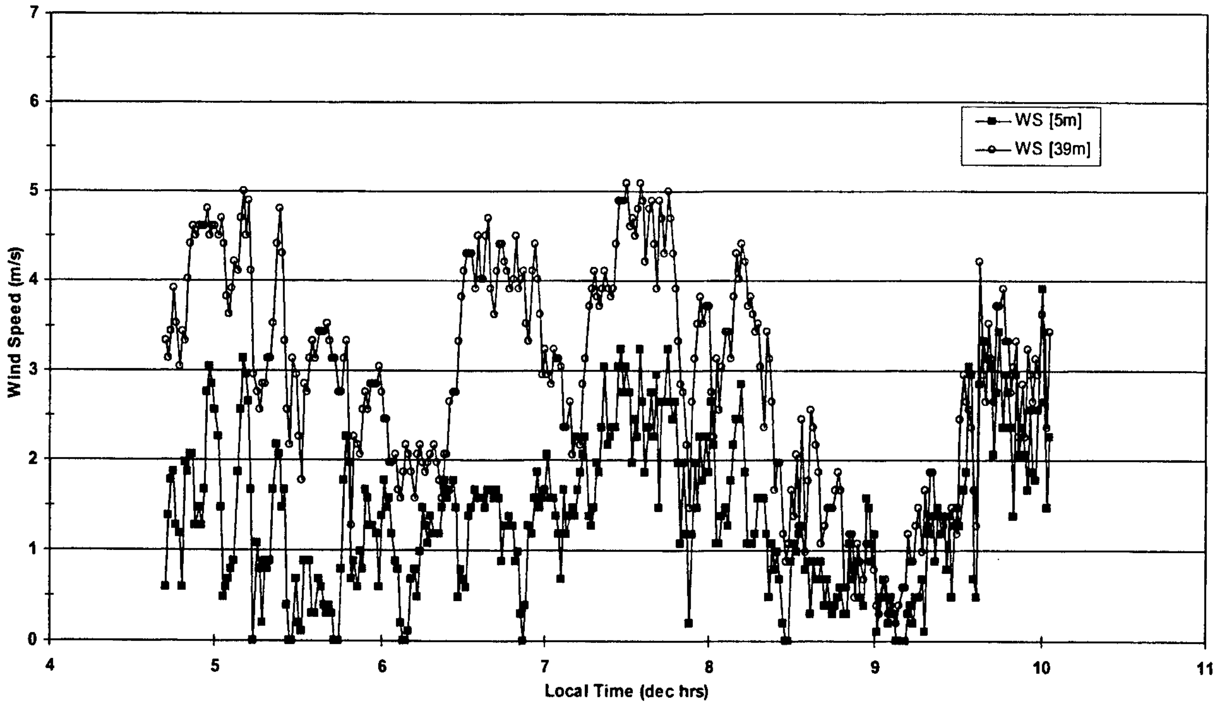



**Figure A17. Thompson Tower-2001 September 20: Wind Speed.**

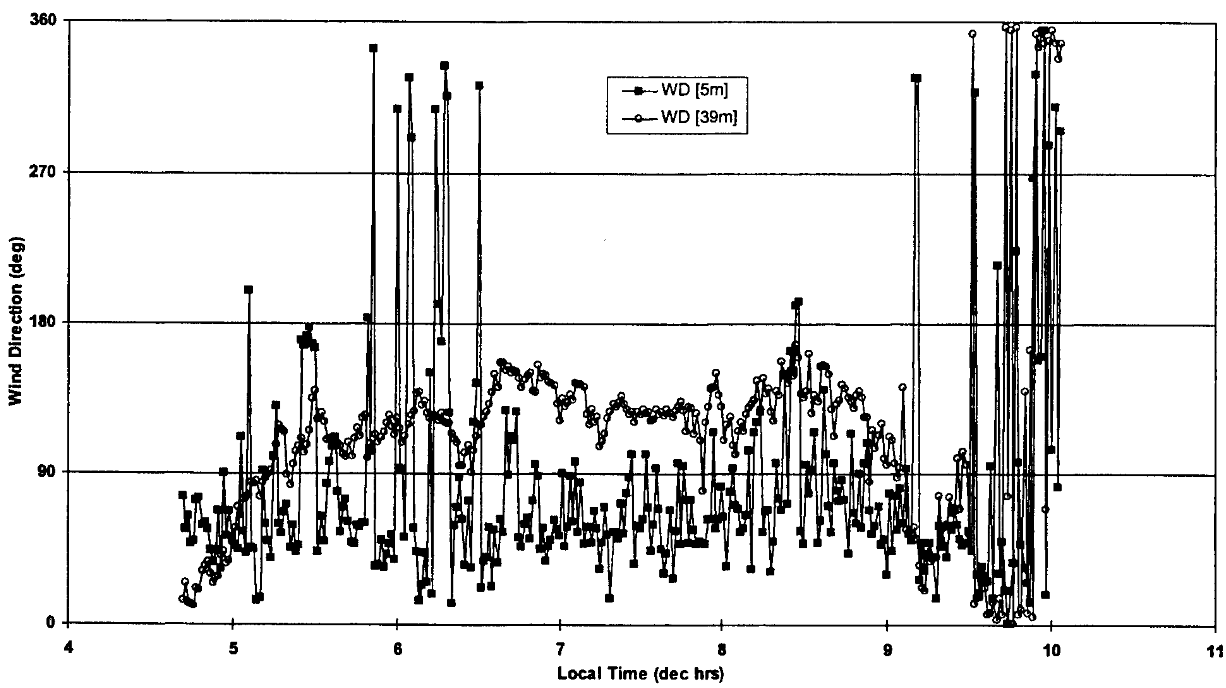



**Figure A18. Thompson Tower-2001 September 20: Wind Direction.**

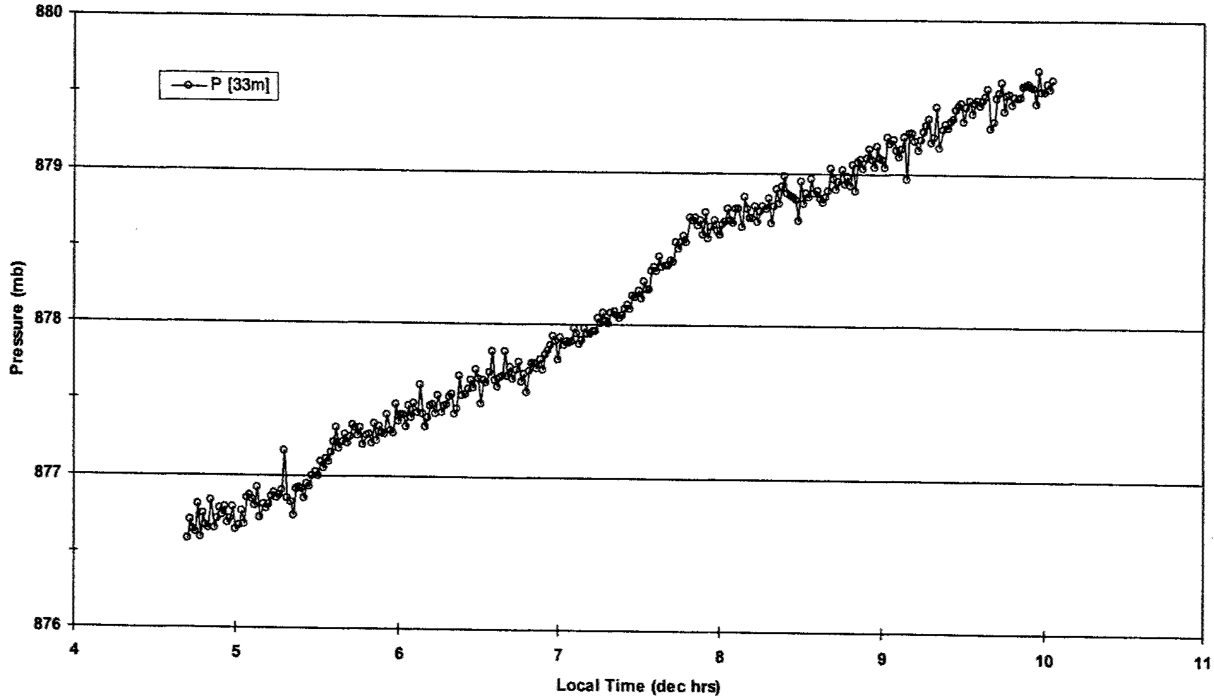



**Figure A19. Thompson Tower-2001 September 20: Pressure.**

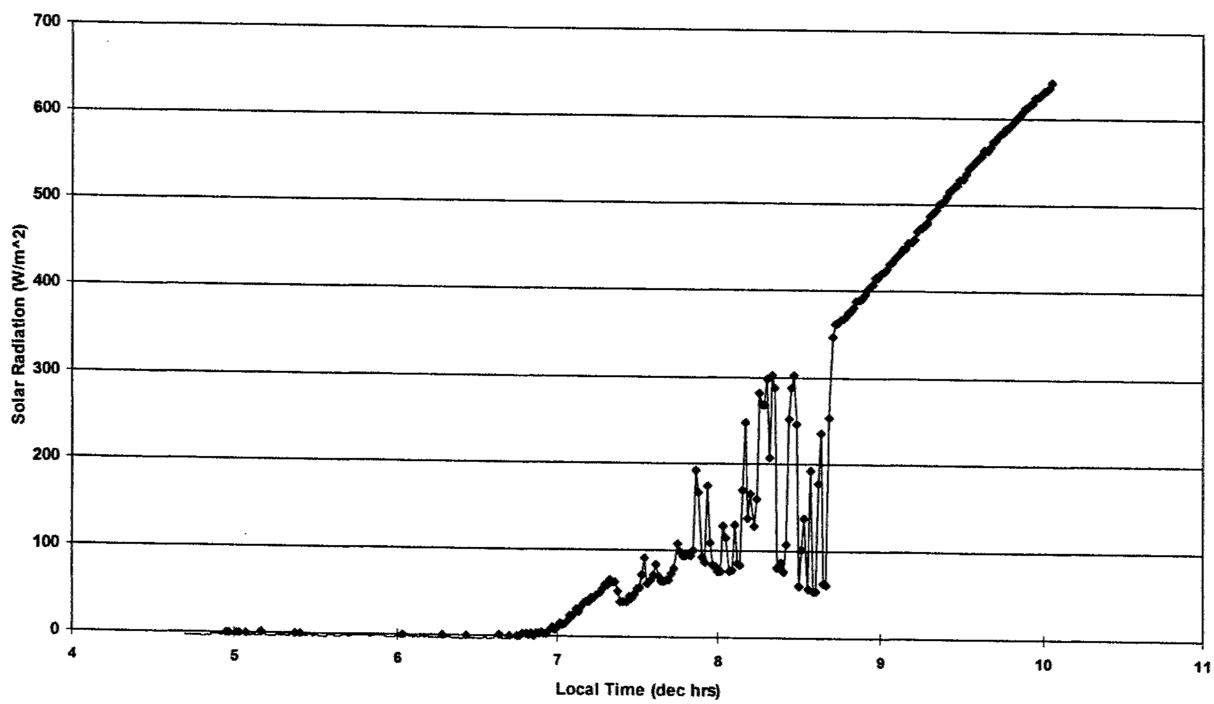



**Figure A20. Thompson Tower-2001 September 20: Solar Radiation.**

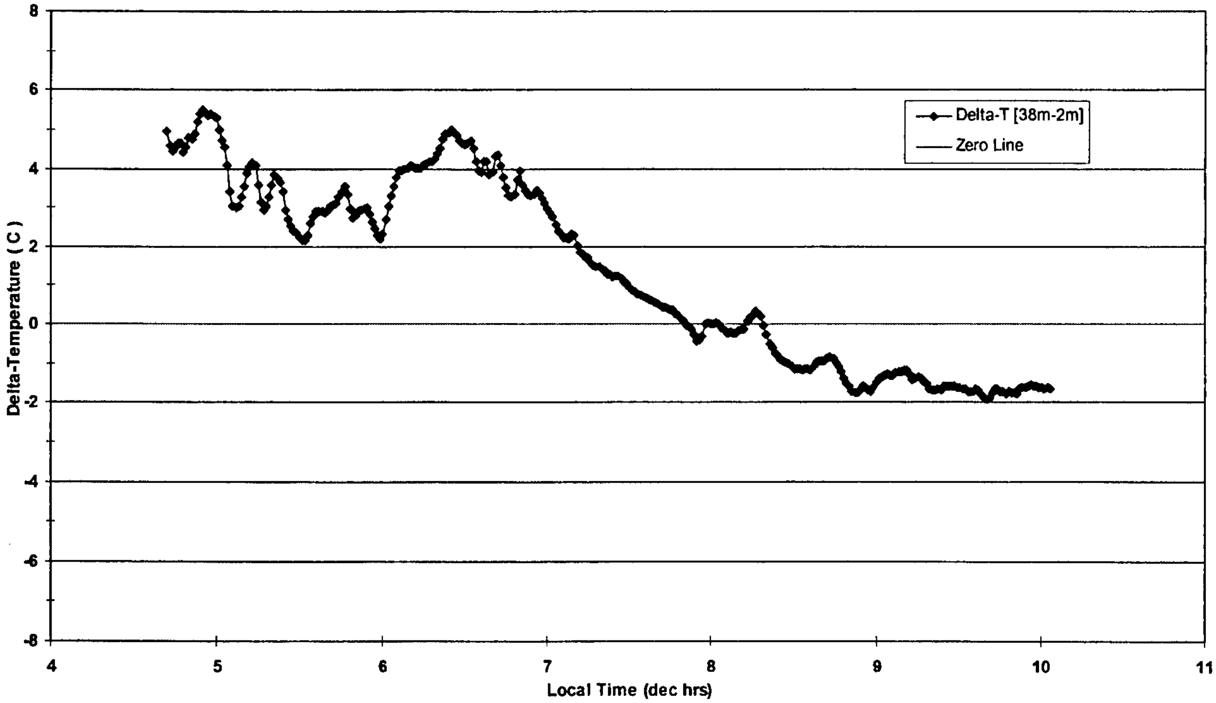



**Figure A21. Thompson Tower-2001 September 20: Delta-T.**

# Figures A22–A28: 2001 September 21-Thompson Tower Data

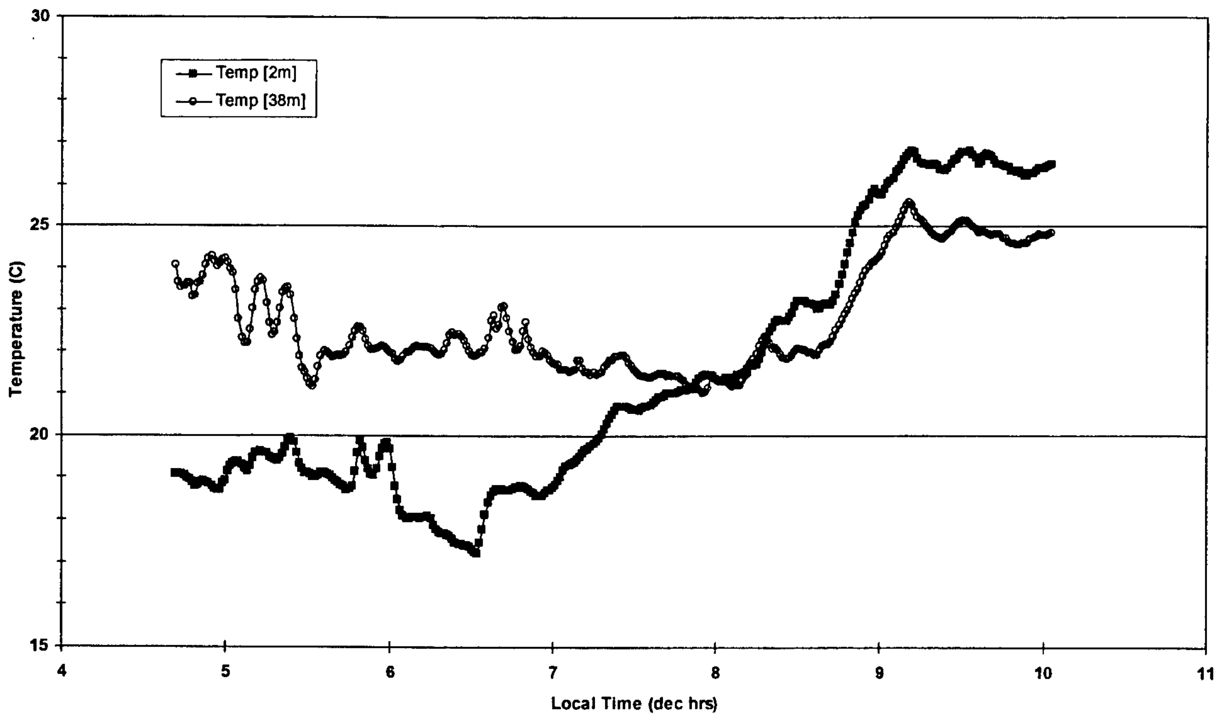



**Figure A22. Thompson Tower-2001 September 21: Temperature.**

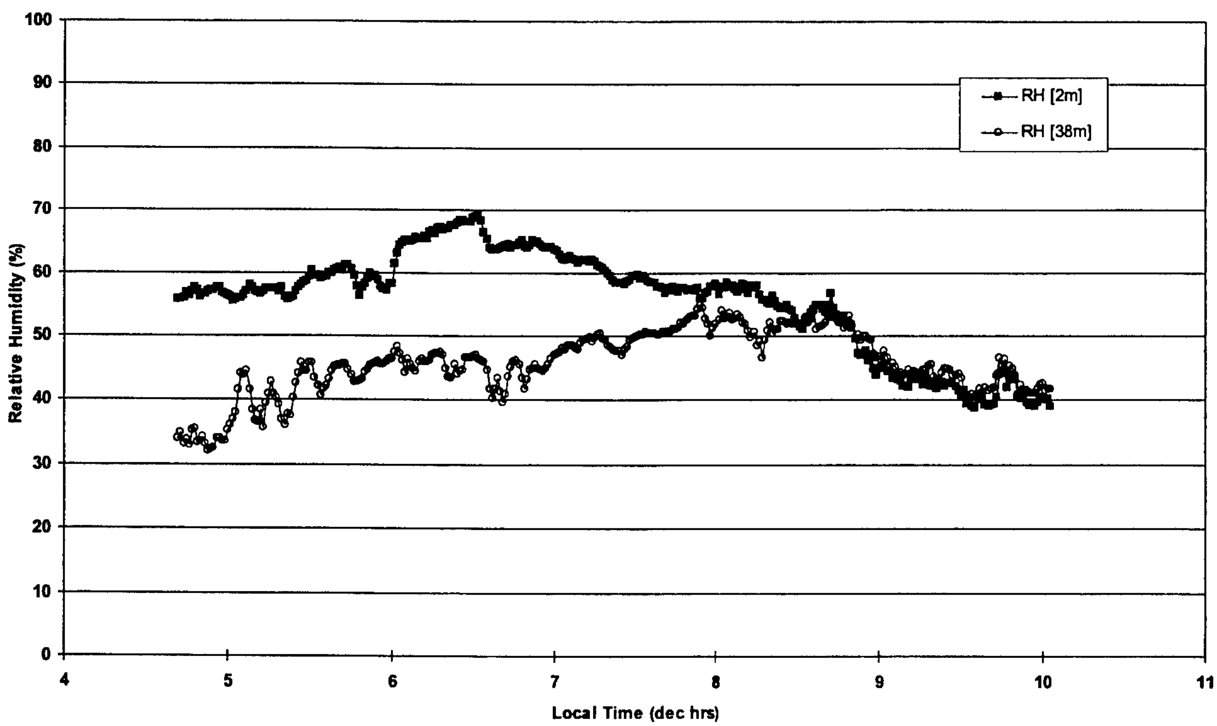



**Figure A23. Thompson Tower-2001 September 21: Relative Humidity.**

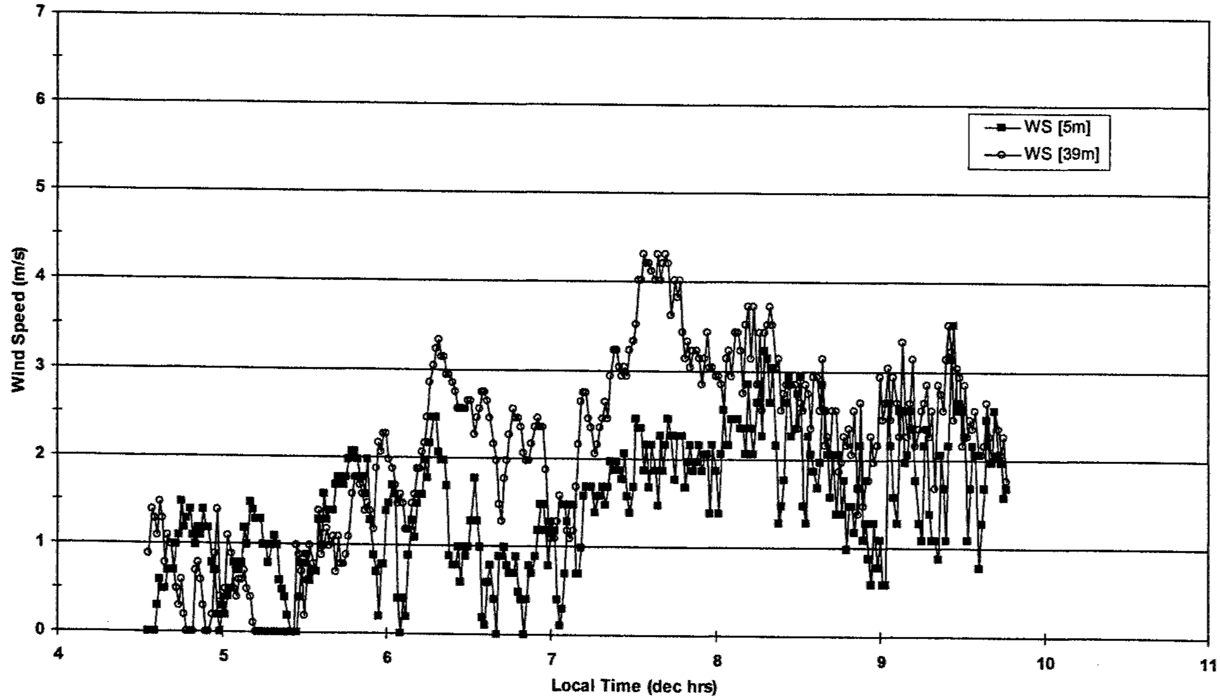



**Figure A24. Thompson Tower-2001 September 21: Wind Speed.**

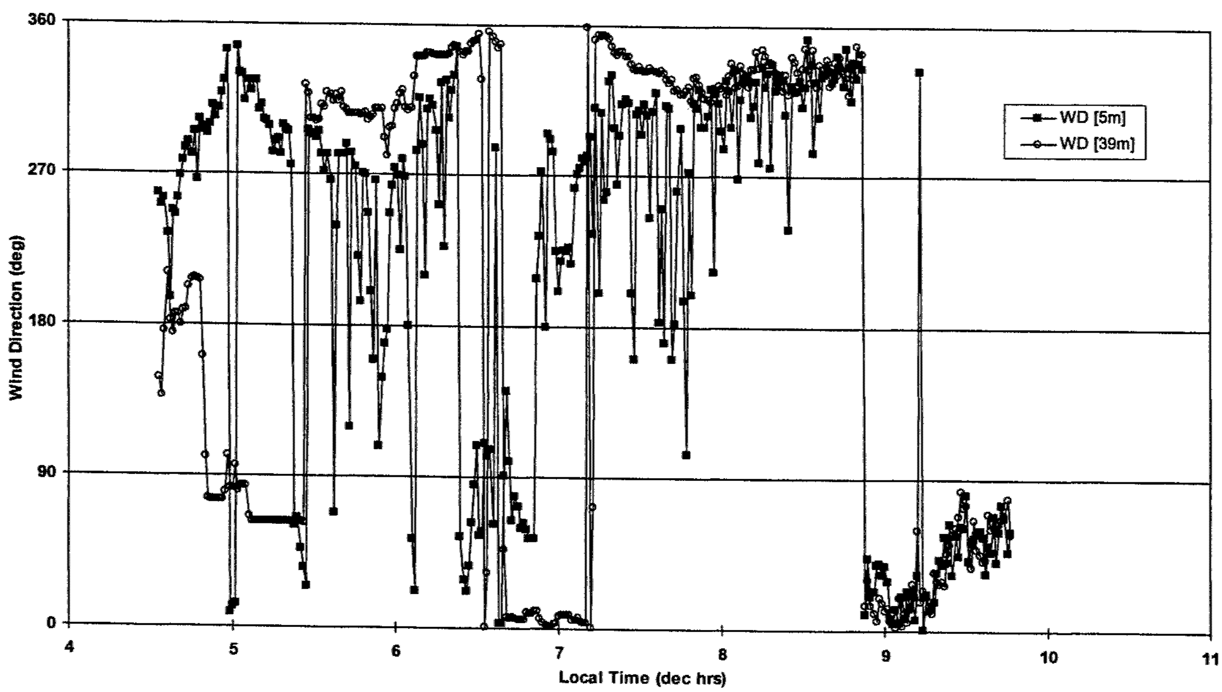



**Figure A25. Thompson Tower-2001 September 21: Wind Direction.**

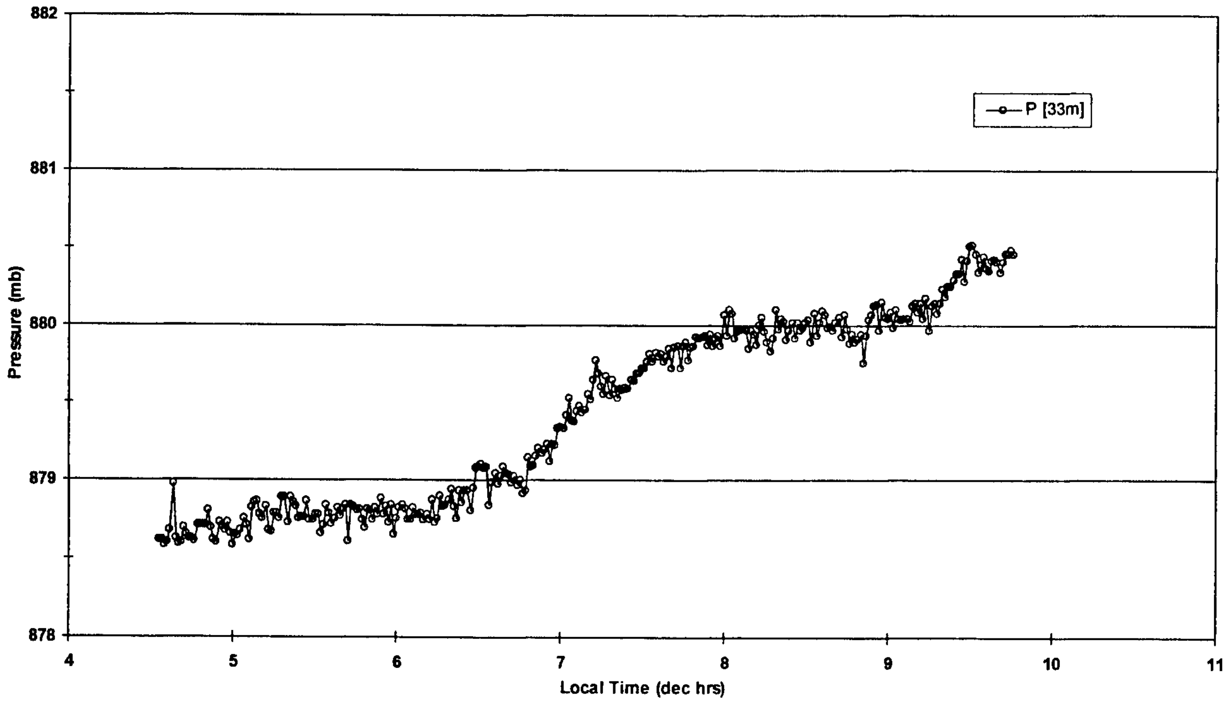



**Figure A26. Thompson Tower-2001 September 21: Pressure.**

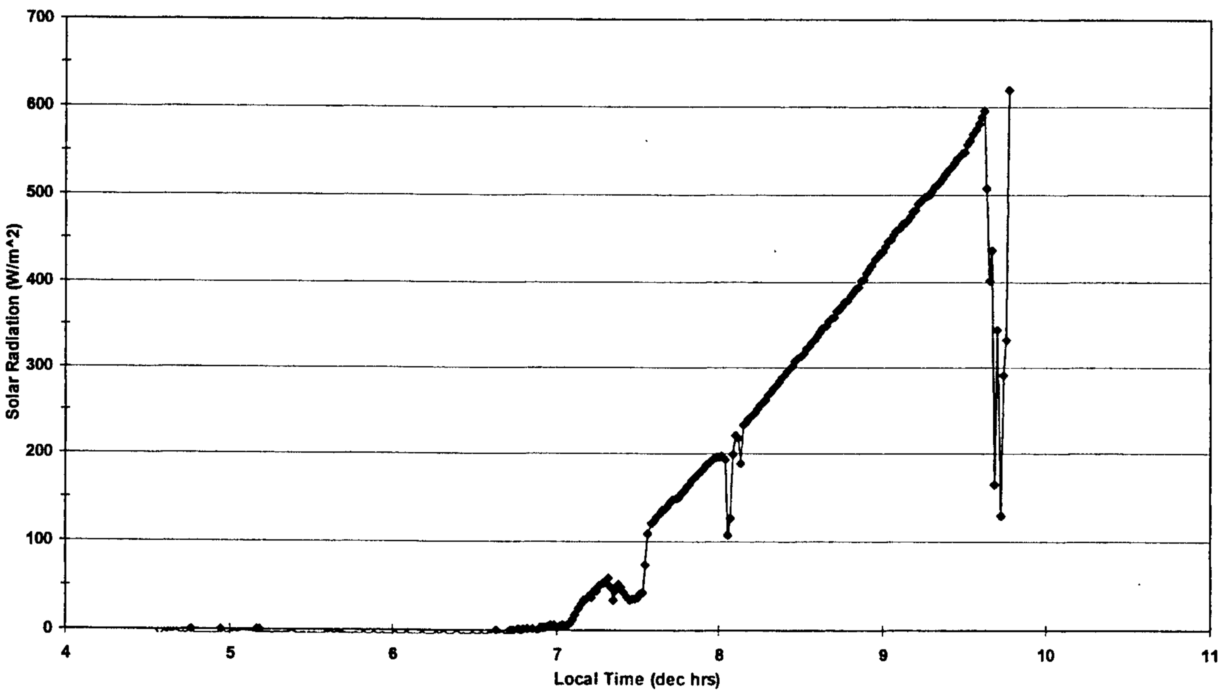



**Figure A27. Thompson Tower-2001 September 21: Solar Radiation.**

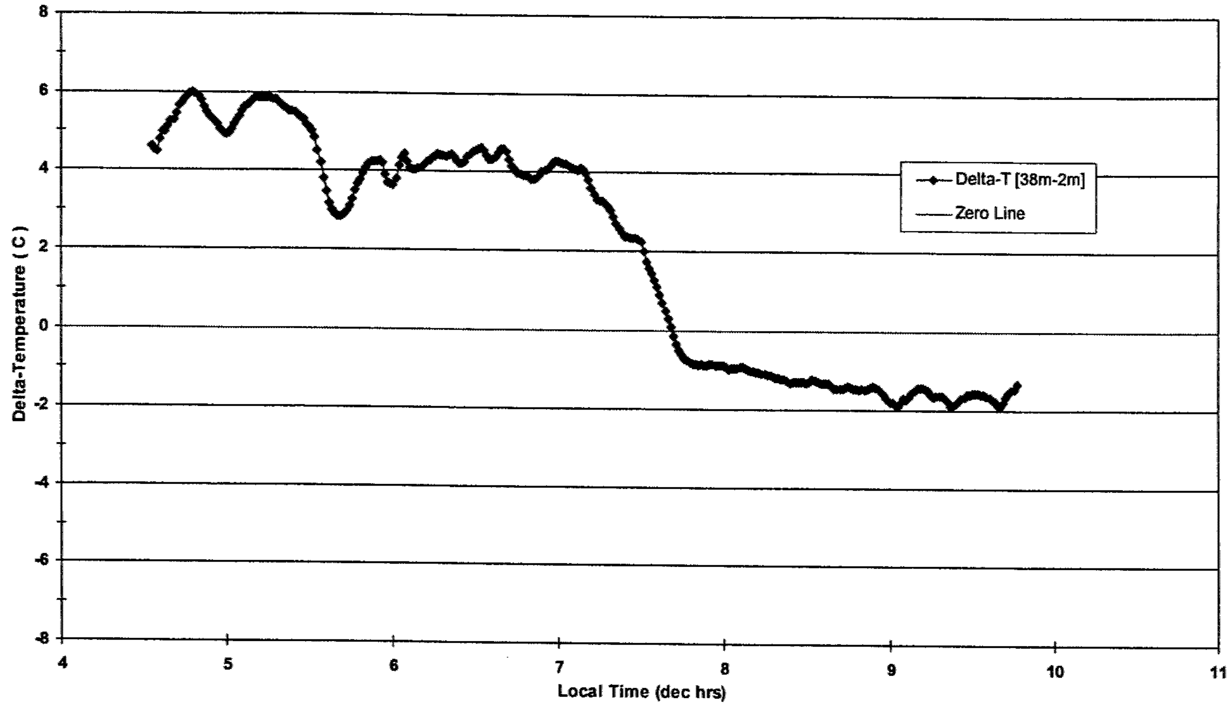



**Figure A28. Thompson Tower-2001 September 21: Delta-T.**

# Appendix B: RAWINSONDE Data

This appendix is part of ARL-TR-2827, Surface Layer Stability Transition Research Minimum Neutral Event-to-Sunrise Time Interval: 2001 September Case Study, U.S. Army Research Laboratory, White Sands Missile Range, NM 88002-5501.

A Lagrangian (following the parcel) perspective on the atmospheric conditions during the Nighttime (Stable) to Daytime (Unstable) transition was quantitatively recorded by the Thompson Site rawinsonde (RAOB) data. A full Test Day's worth of data is presented on a single plot. The earliest Sub-case (Stable) is designated with a red solid box; an orange open circle shows the Neutral Sub-case; the Unstable Sub-case is a green solid triangle and any additional Unstable data is a blue open diamond. We have purposefully elected to follow the rainbow's spectrum to make data viewing easier. As a reminder, the general times designated for each Sub-case were:

| | |
|---|---|
| Stable | 0500–0700 MDT |
| Neutral | 0700–0900 MDT |
| Unstable | 0900–1100 MDT |

The 1554 MDT, 2001 September 18 Pre-Test data were included for completeness. The following are the four sections of Appendix B:

- Figures B1–B4: 2001 September 18 (Wind Speed and Wind Direction were not available for September 18)
- Figures B5–B10: 2001 September 19
- Figures B11–B16: 2001 September 20
- Figures B17–B23: 2001 September 21

**Figures B1–B4: 2001 September 18-Rawinsonde Data**

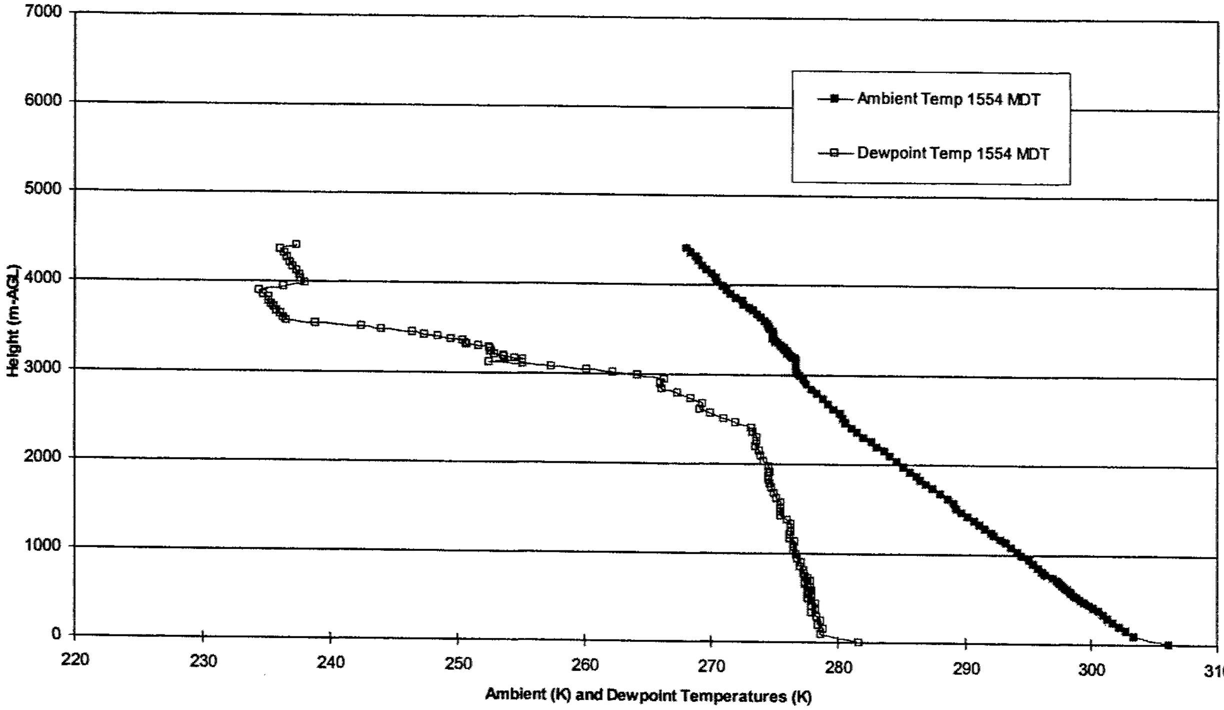



**Figure B1. Thompson Tower RAOB Launch-2001 September 18: Temperature.**

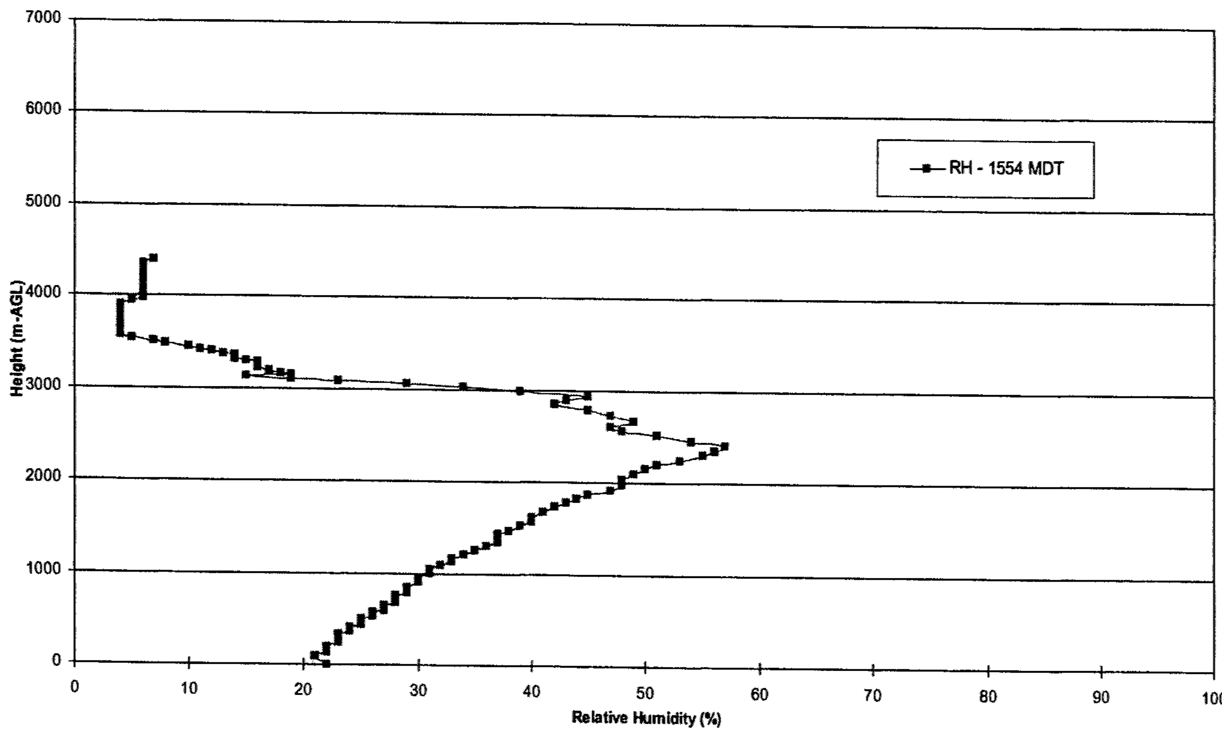



**Figure B2. Thompson Tower RAOB Launch-2001 September 18: Relative Humidity.**

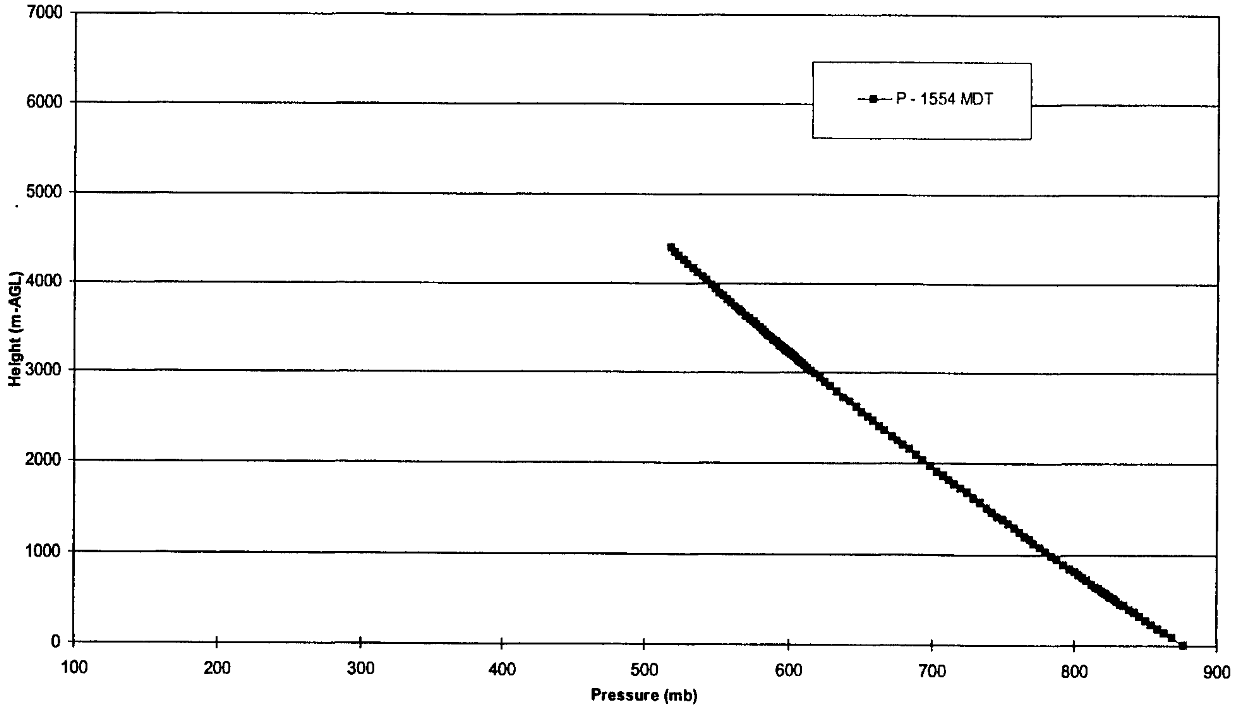



**Figure B3. Thompson Tower RAOB Launch-2001 September 18: Pressure.**

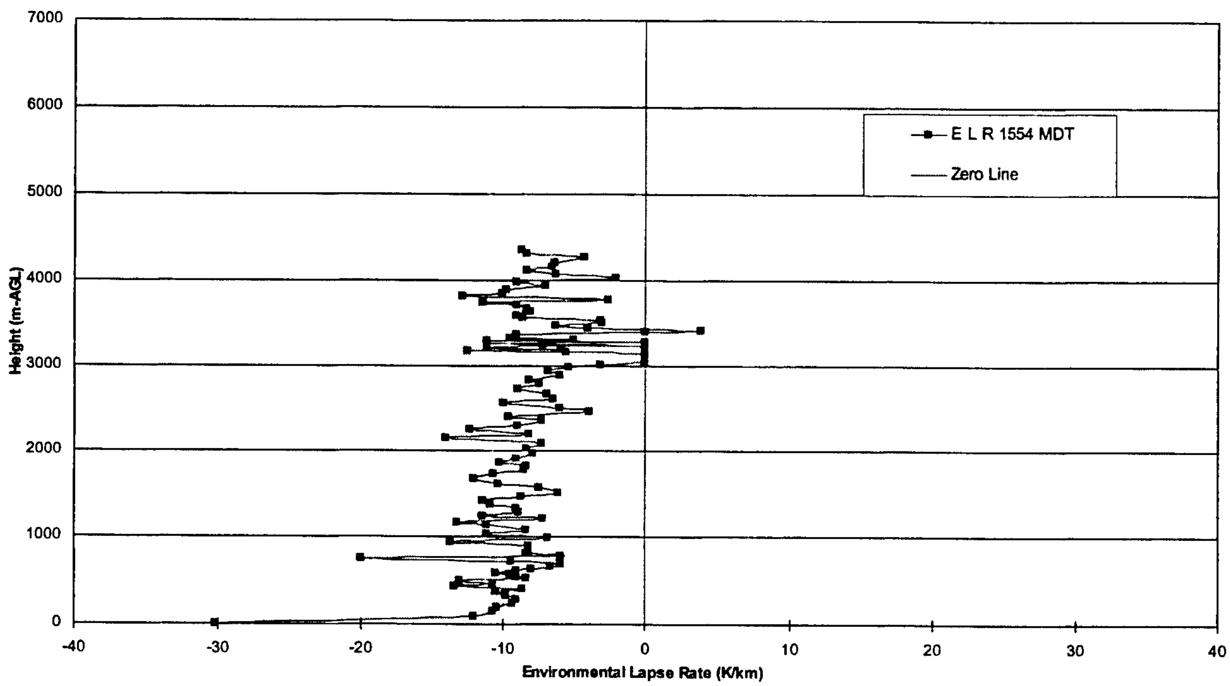



**Figure B4. Thompson Tower RAOB Launch-2001 September 18: ELR.**

## Figures B5–B10: 2001 September 19-Rawinsonde Data

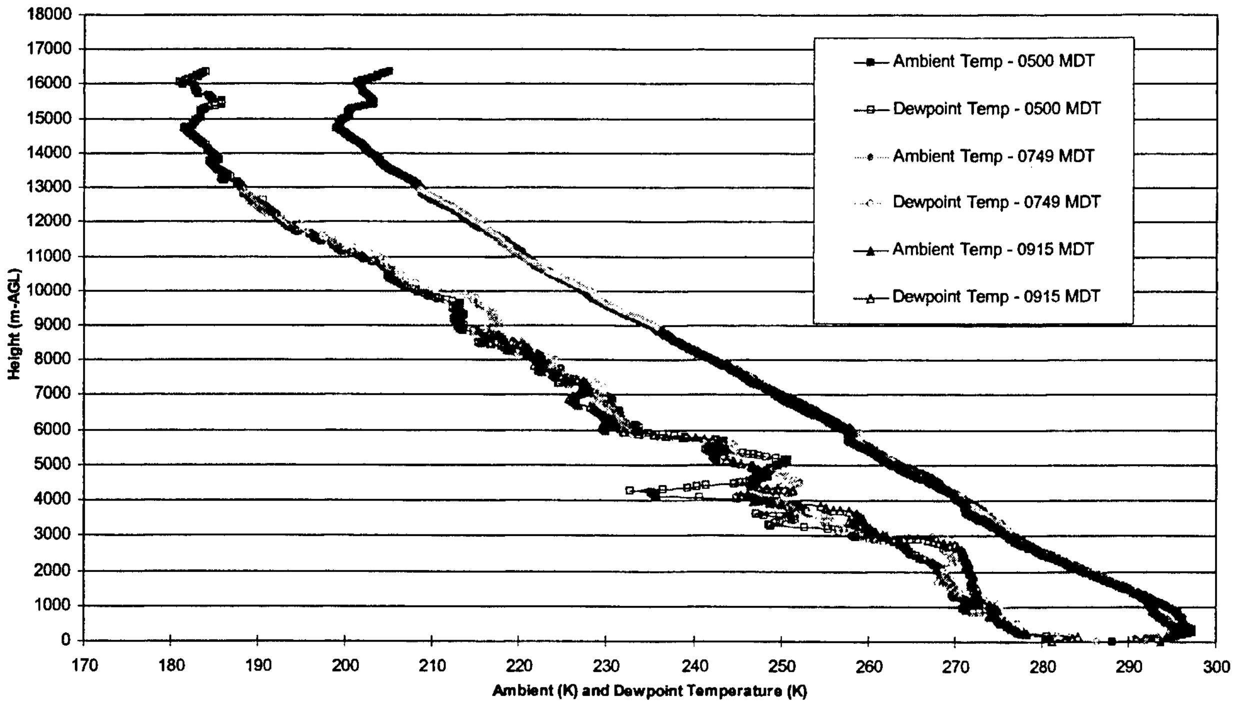



**Figure B5. Thompson Tower RAOB Launch-2001 September 19: Temperature.**

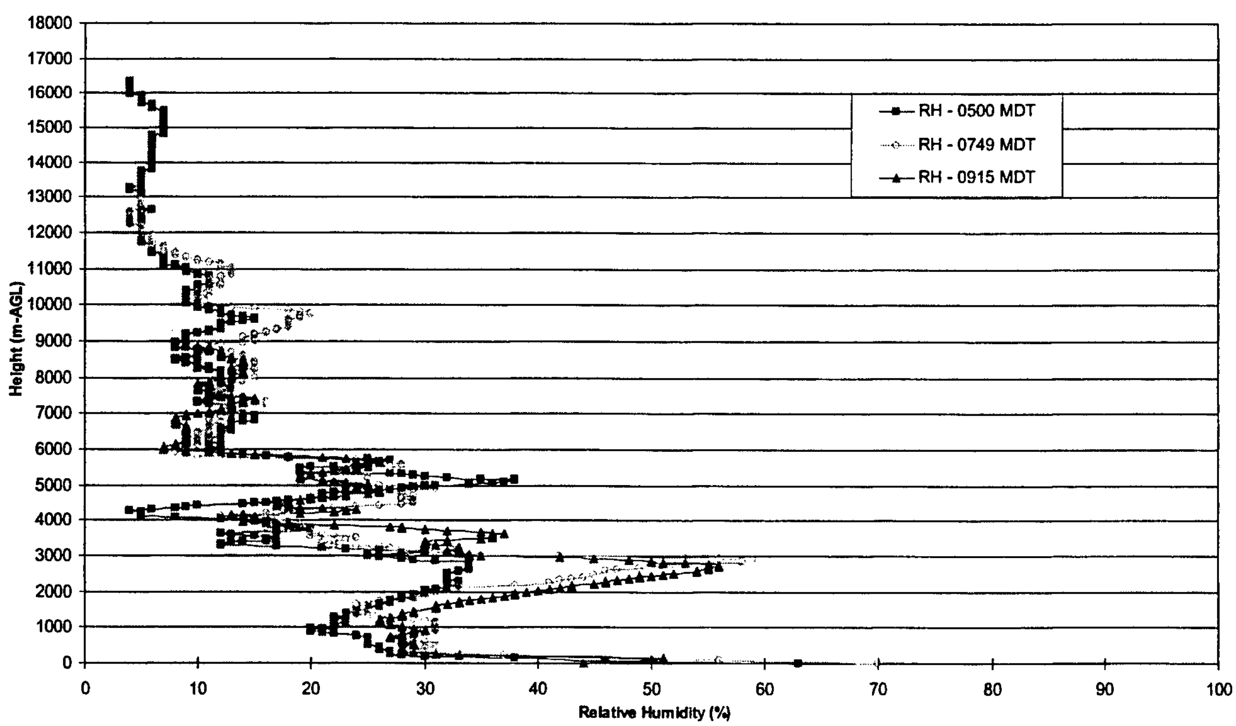



**Figure B6. Thompson Tower RAOB Launch-2001 September 19: Relative Humidity.**

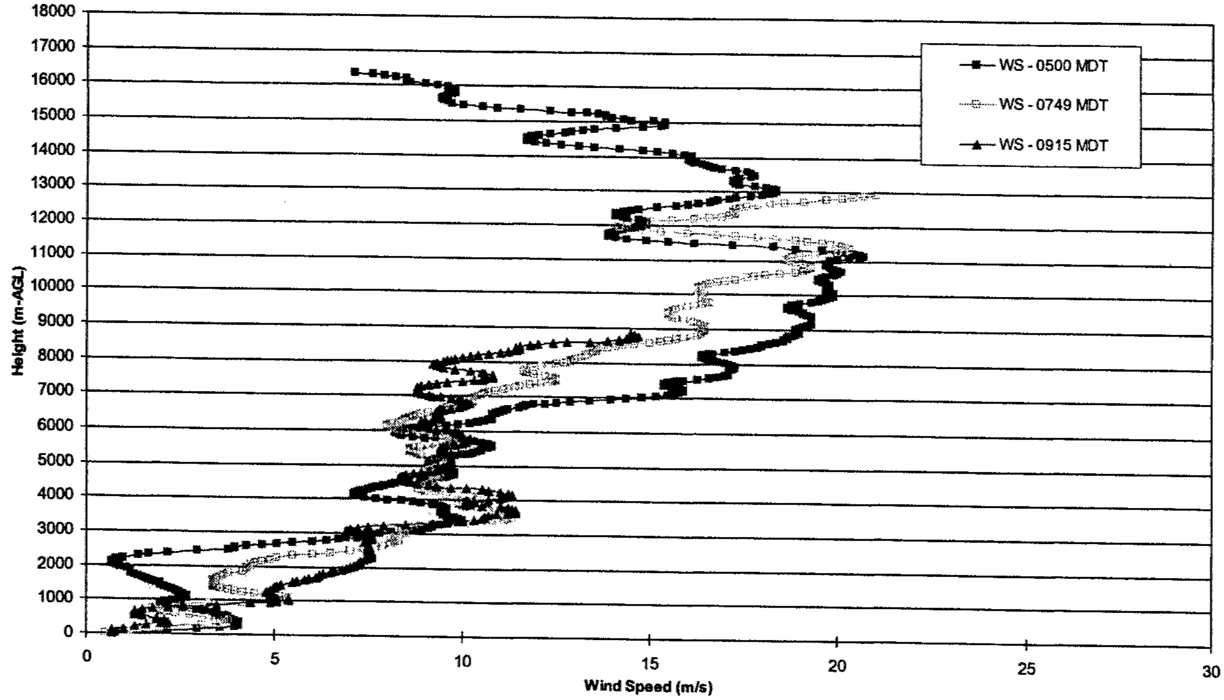



**Figure B7. Thompson Tower RAOB Launch-2001 September 19: Wind Speed.**

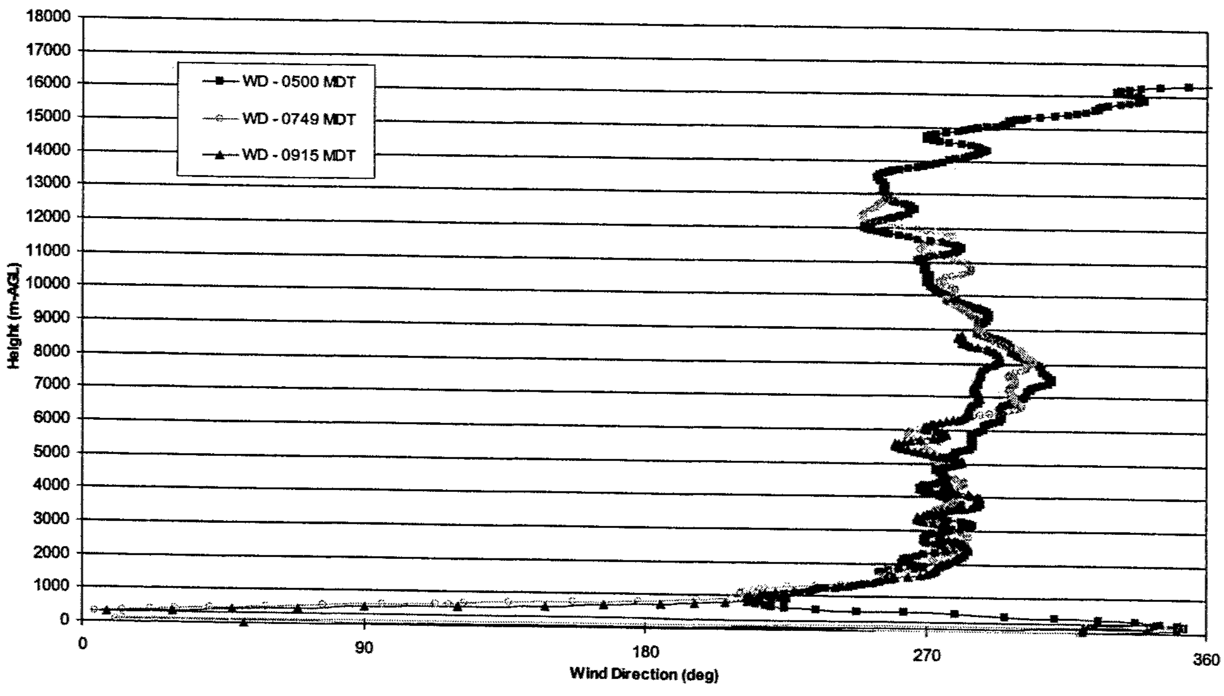



**Figure B8. Thompson Tower RAOB Launch-2001 September 19: Wind Direction.**

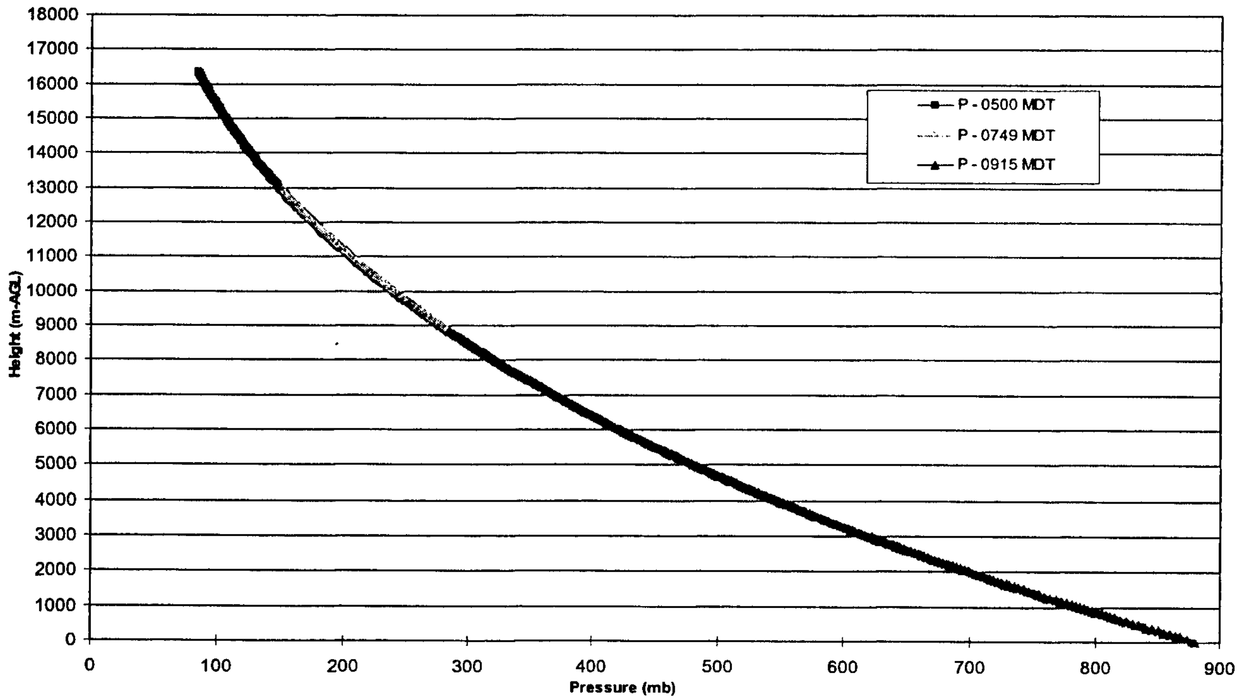



**Figure B9. Thompson Tower RAOB Launch-2001 September 19: Pressure.**

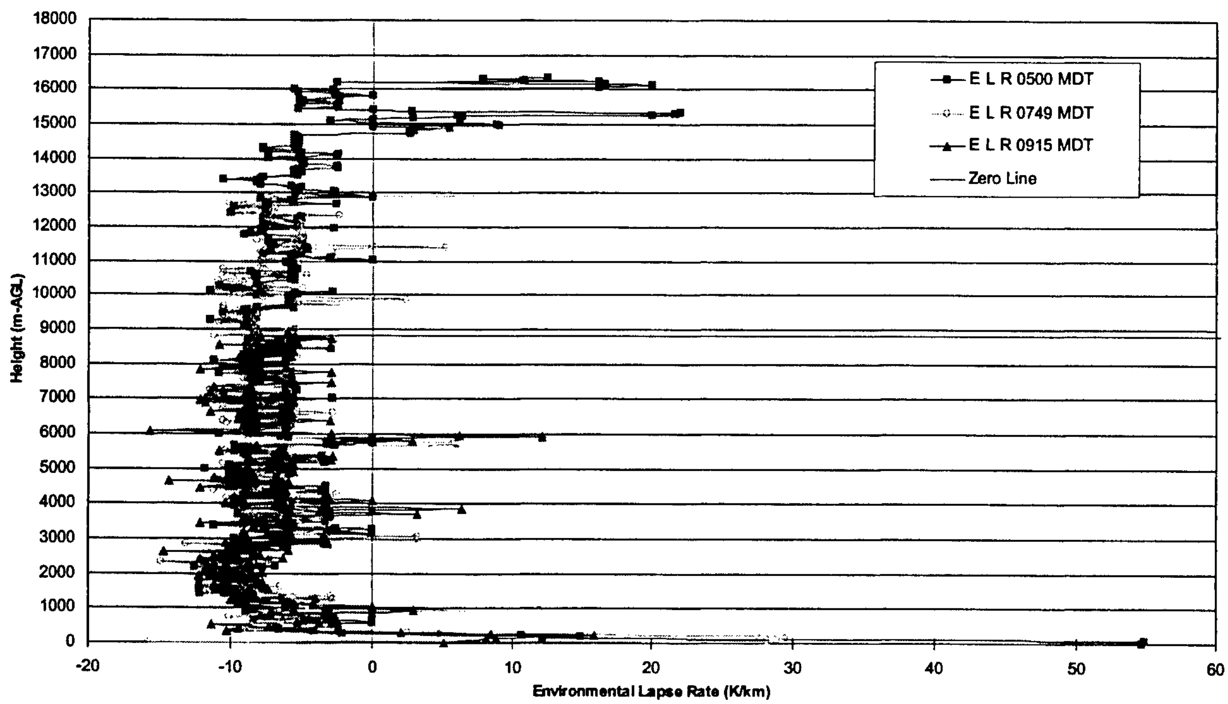



**Figure B10. Thompson Tower RAOB Launch-2001 September 19: ELR.**

## Figures B11–B16: 2001 September 20-Rawinsonde Data

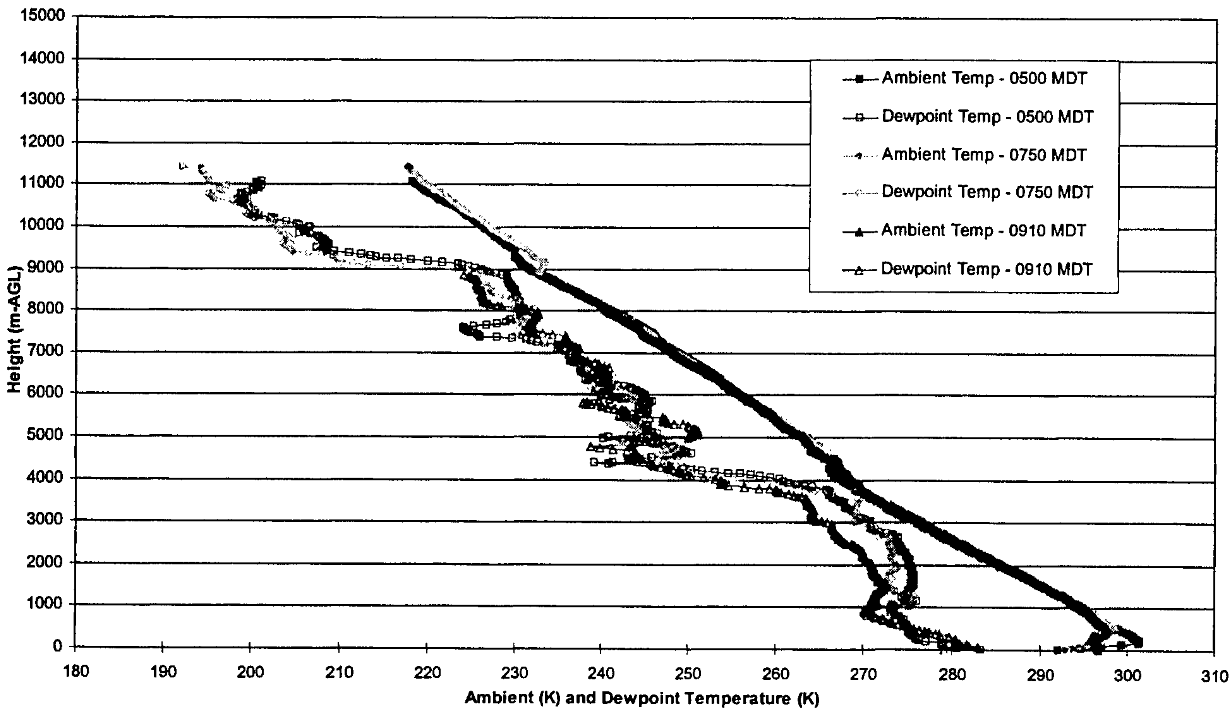



**Figure B11. Thompson Tower RAOB Launch-2001 September 20: Temperature.**

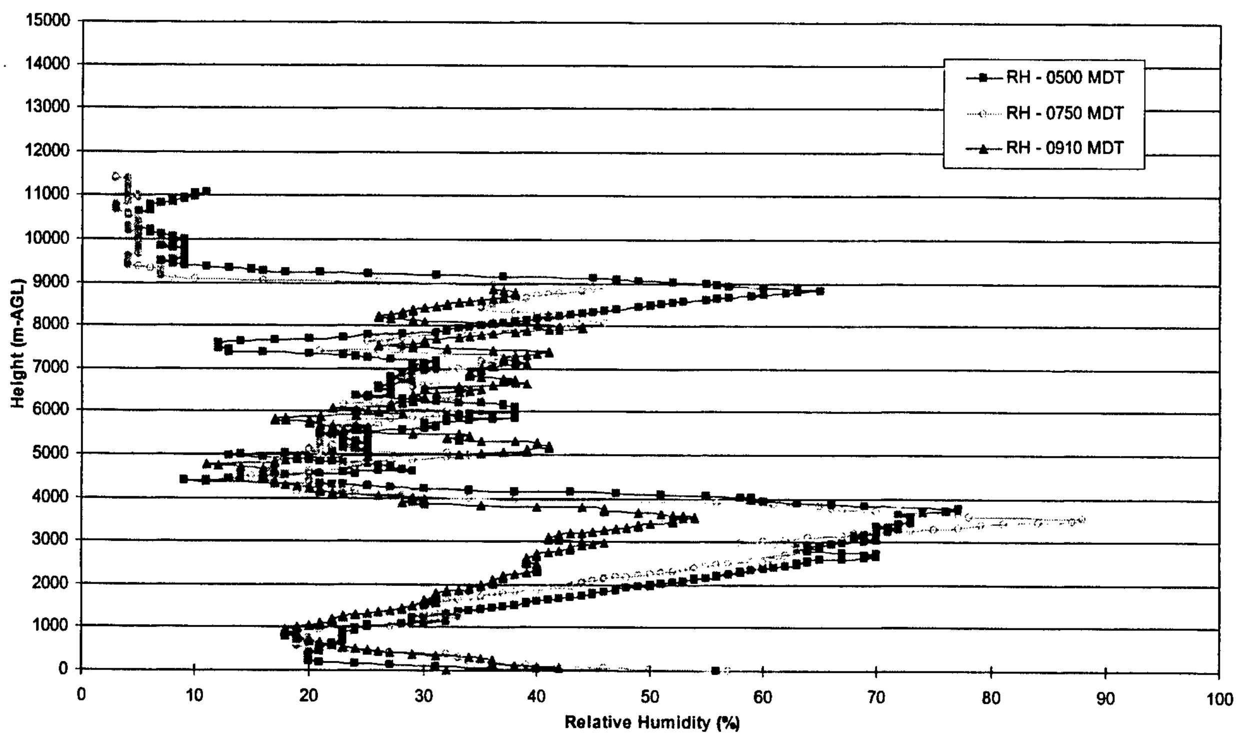



**Figure B12. Thompson Tower RAOB Launch-2001 September 20: Relative Humidity.**

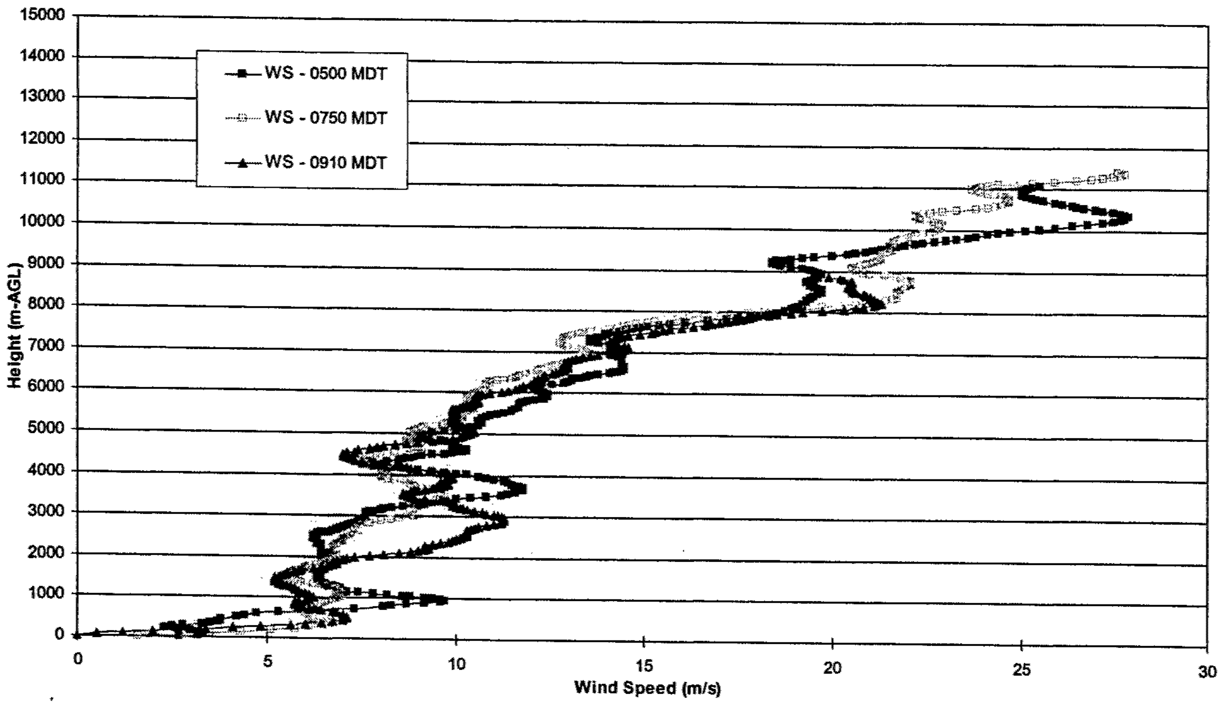



**Figure B13. Thompson Tower RAOB Launch-2001 September 20: Wind Speed.**

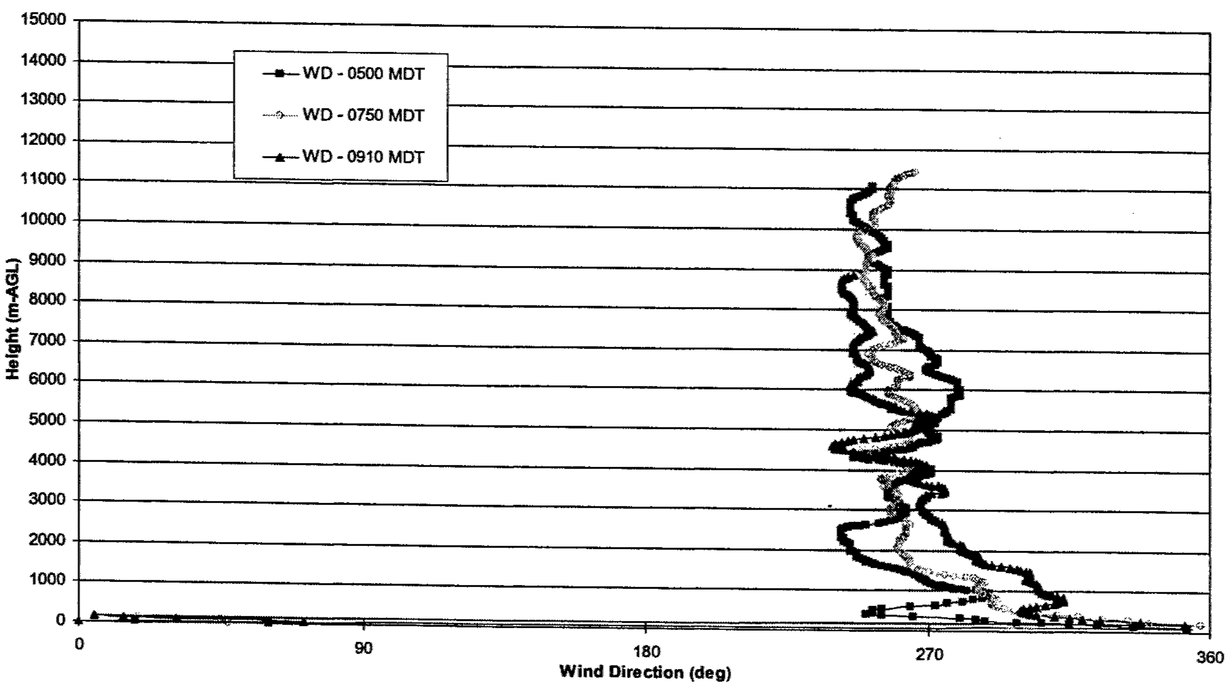



**Figure B14. Thompson Tower RAOB Launch-2001 September 20: Wind Direction.**

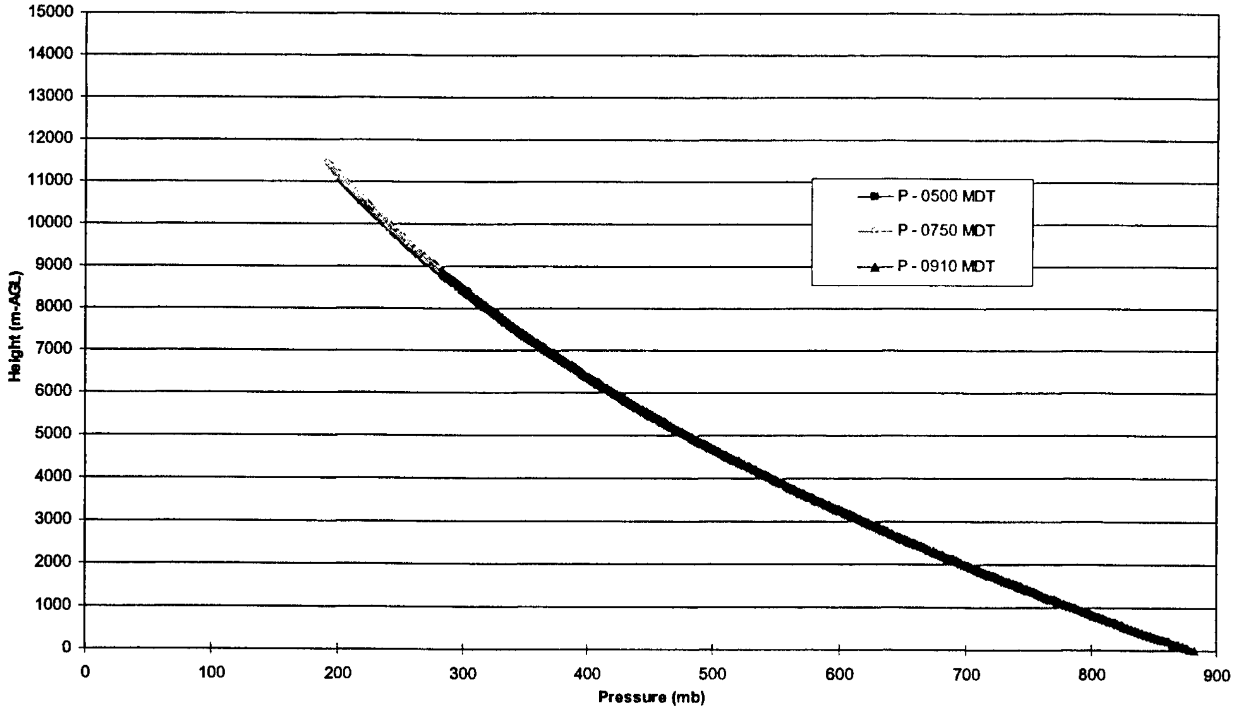



**Figure B15. Thompson Tower RAOB Launch-2001 September 20: Pressure.**

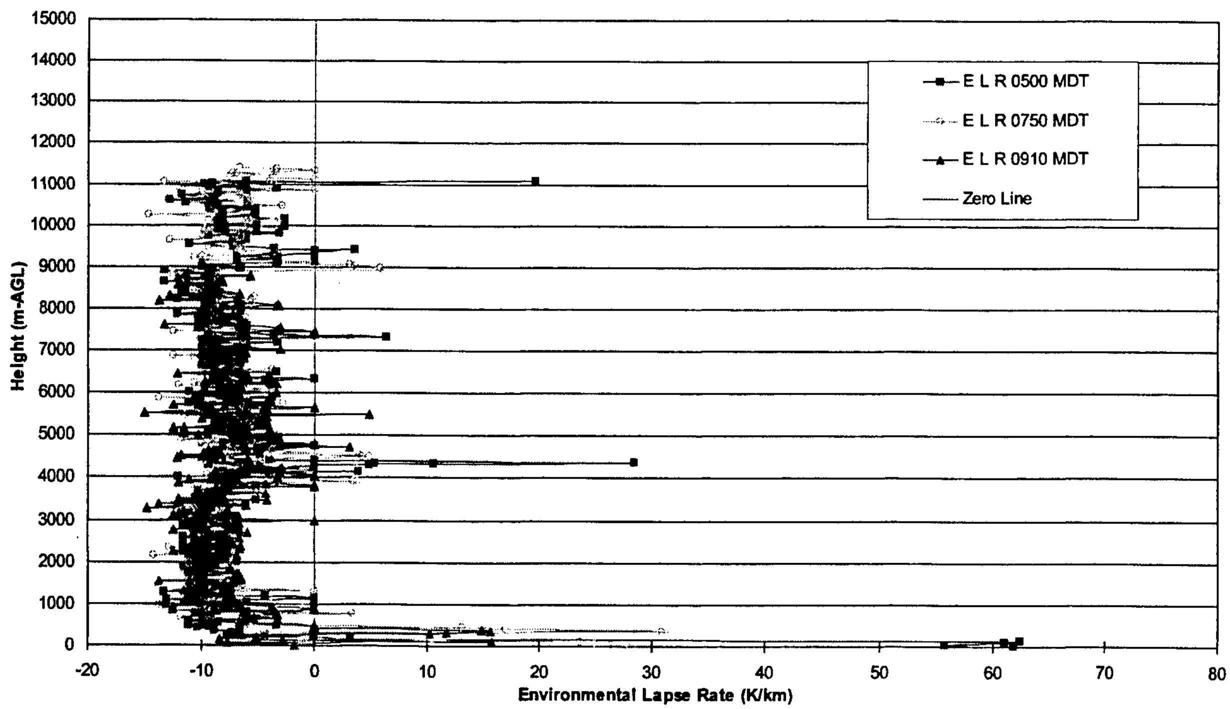



**Figure B16. Thompson Tower RAOB Launch-2001 September 20: ELR.**

**Figures B17–B22: 2001 September 21-Rawinsonde Data**

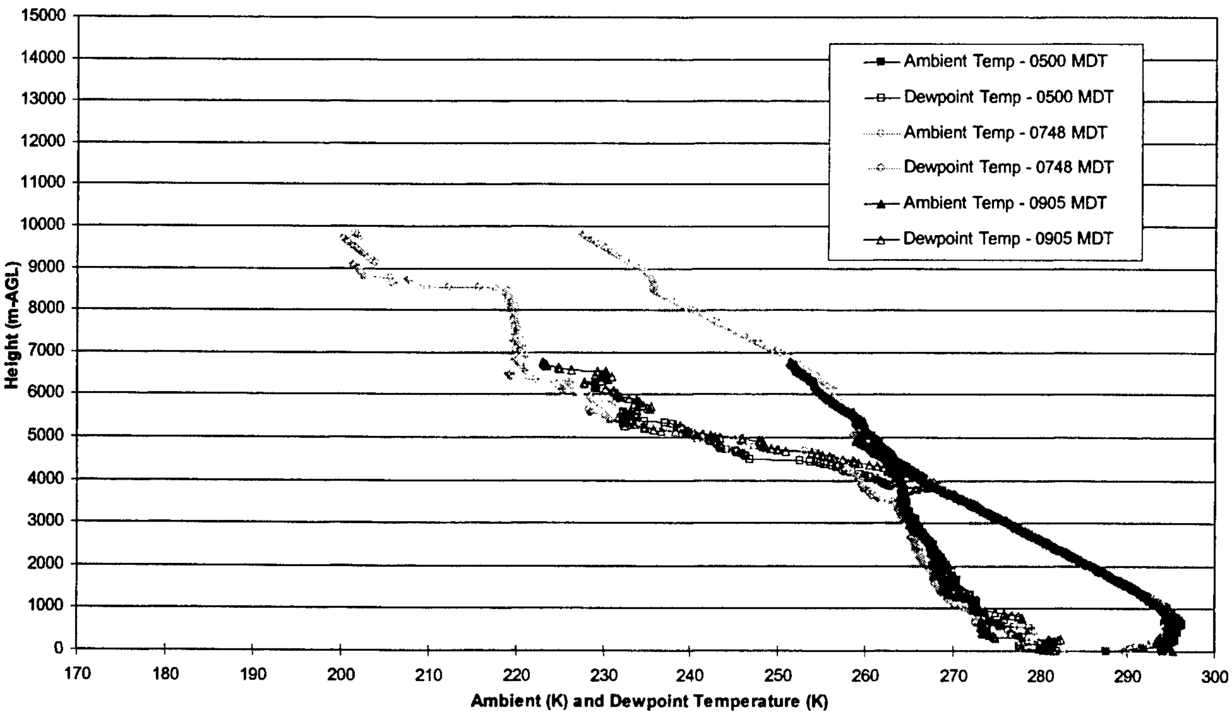



**Figure B17. Thompson Tower RAOB Launch-2001 September 21: Temperature.**

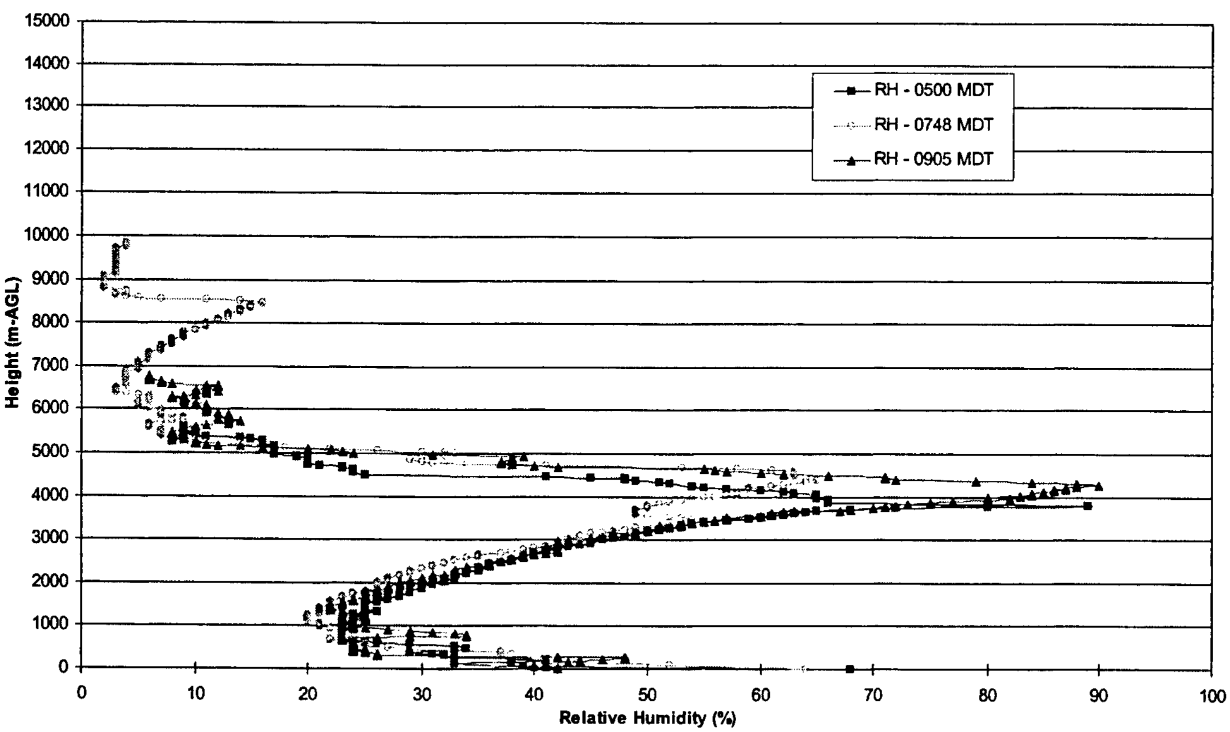



**Figure B18. Thompson Tower RAOB Launch-2001 September 22: Relative Humidity.**

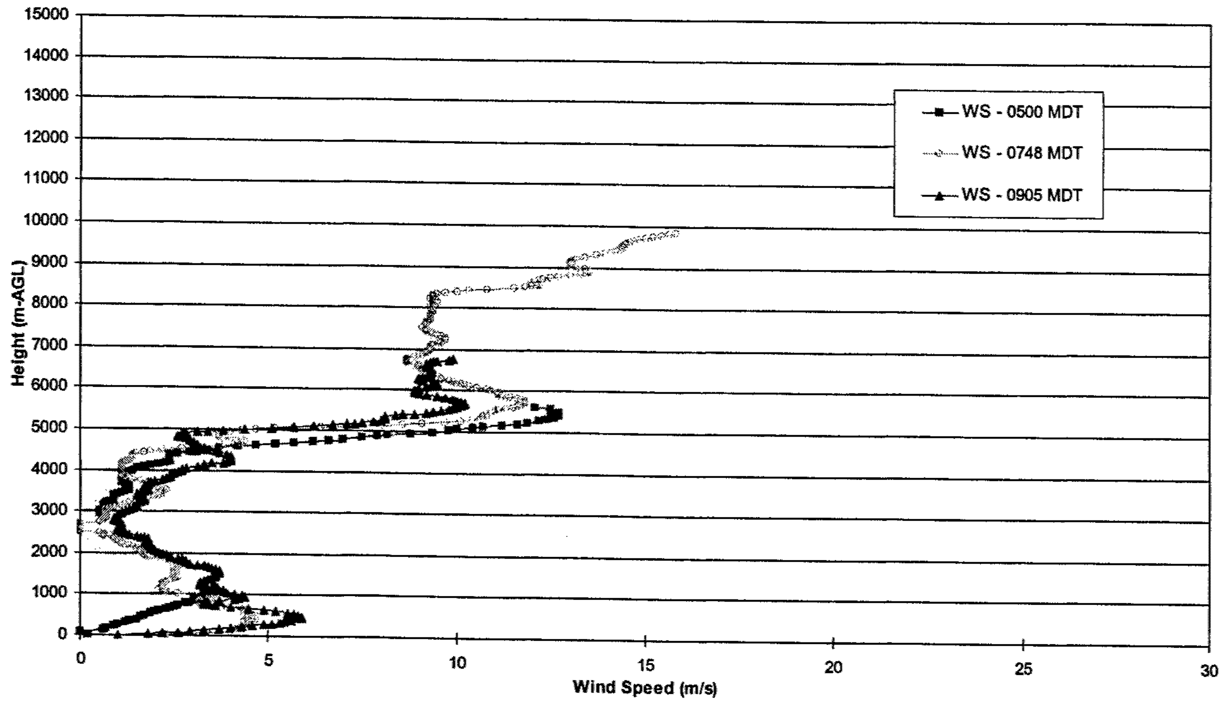



**Figure B19. Thompson Tower RAOB Launch-2001 September 21: Wind Speed.**

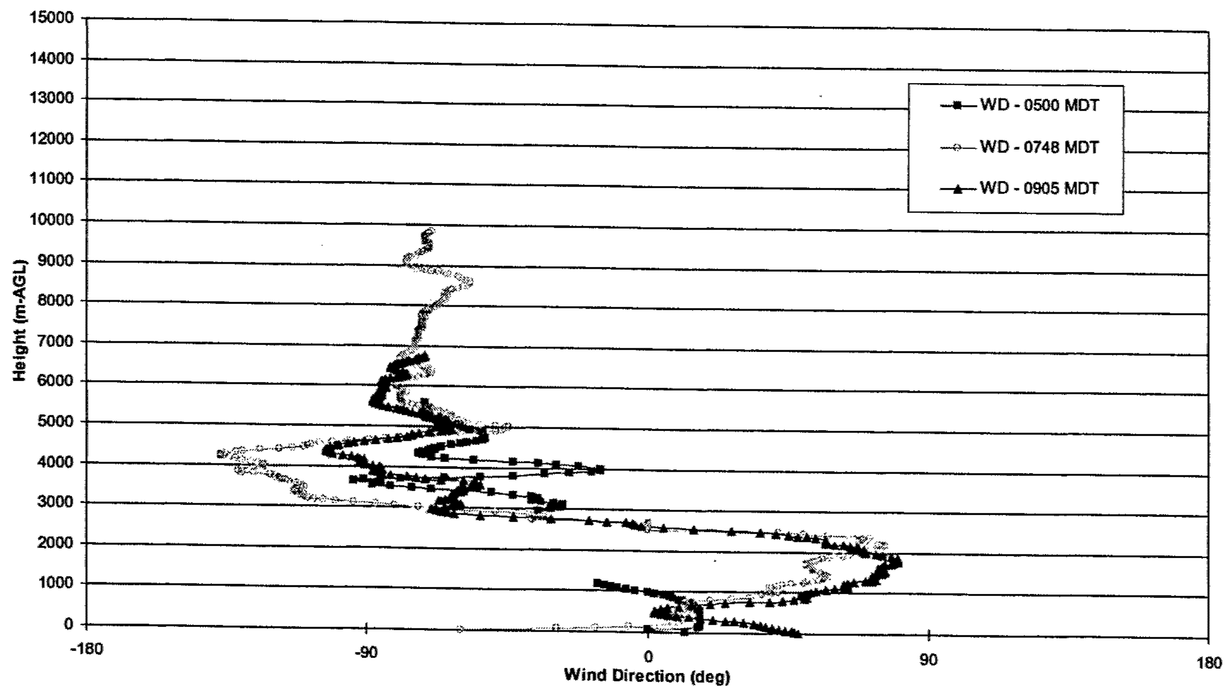



**Figure B20. Thompson Tower RAOB Launch-2001 September 21: Wind Direction.**

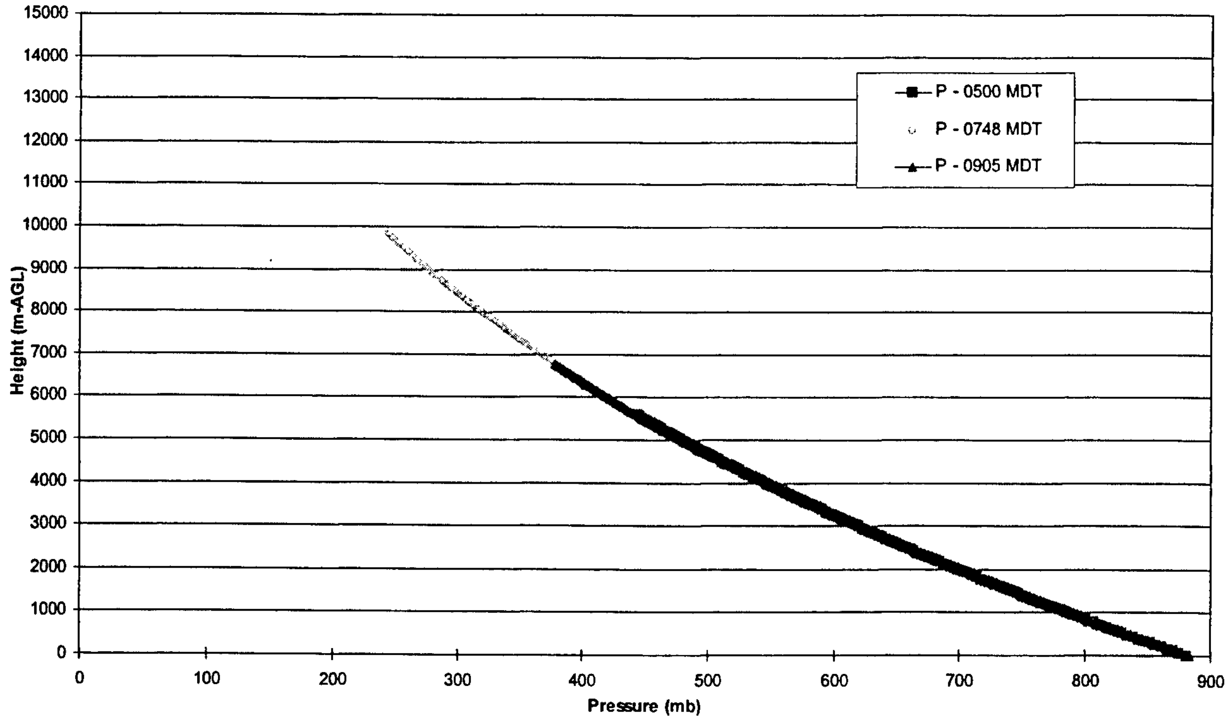



**Figure B21. Thompson Tower RAOB Launch-2001 September 21: Pressure.**

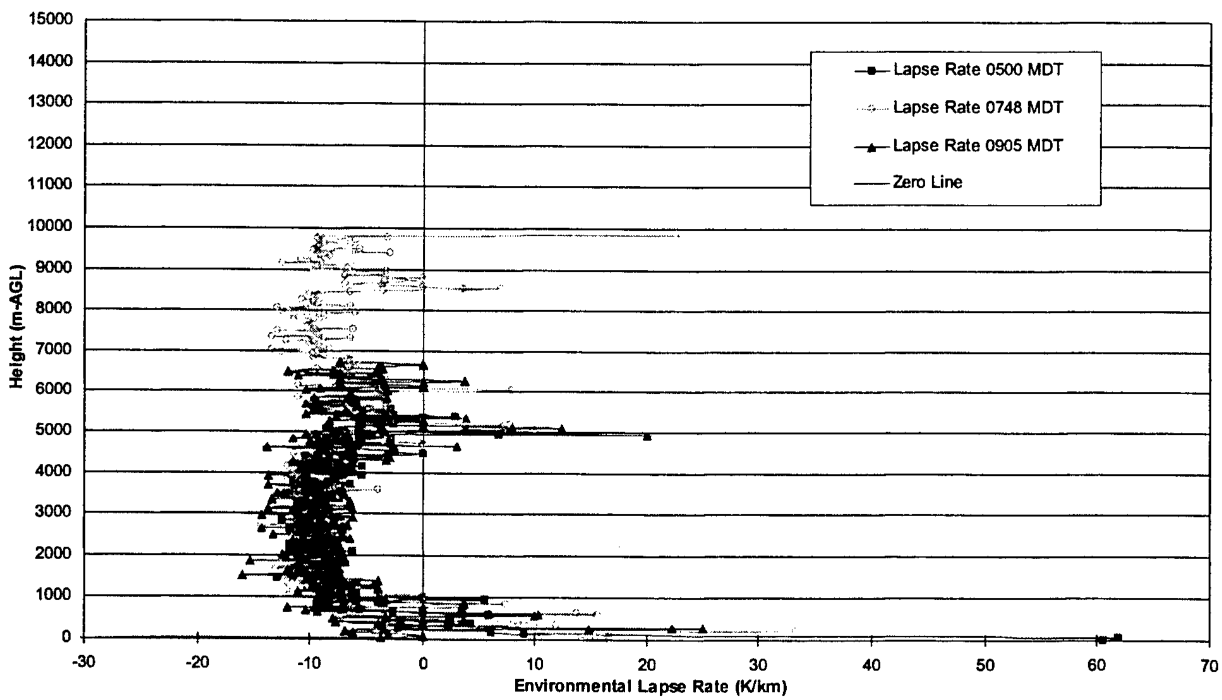



**Figure B22. Thompson Tower RAOB Launch-2001 September 21: ELR.**

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**13. SUPPLEMENTARY NOTES**

**14. ABSTRACT**

Near surface target acquisition and EO propagation significantly improve during the Surface Layer Stability Transition (SLST). Thus, this research expands Army Chief of Staff Shinseki's vision from "to see first" to, "to see better." The SLST is also the starting and ending points for the atmospheric convection growth phase, an important factor in chemical warfare modeling.

In 2001, the Meteorological-sensors Integration Team of the Army Research Laboratory conducted the last of three field experiments with the primary purpose of characterizing, modeling and exploiting repeatable patterns in the lower portion of the atmospheric boundary layer. The repeatable patterns investigated were the morning Stability Transitions (ST) or Neutral Events (NE). The 2001 September 19–21 test dates were selected based on a forecasted minimal time interval between the local Sunrise and an Ideal case NE. Two previous field tests addressed the other minimum (March 2001) and a maximum (June 2001) Sunrise-to-NE time interval. These Tests are documented separately.

This Surface Layer Stability Transition research pursued two measurement and analysis methods: Eulerian (Tower Data) and quasi-Lagrangian (Rawinsonde data). The Experiment's results validated the Neutral Event Forecast Model, in that all three days showed a ST during the forecasted ST time period. Examples of extended and multiple STs were documented by the data, further enhancing the characterization of a desert stable-neutral-unstable morning transition over the Equinox time period. The information documented in this report serves as a useful building block in support of the primary goal.

**15. SUBJECT TERMS**

Stability Transition, Neutral Events, Non-Ideal Conditions, Boundary Layer, Extended and Multiple Neutral Events

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